Saskatchewan
Agriculture, Food
and Rural
Revitalization

ADF

AGRICULTURE DEVELOPMENT FUND

FINAL REPORT

19970299

THE LONG-TERM EFFECT OF REPEATED APPLICATION OF HOG MANURE ON SOIL PRODUCTIVITY AND ON THE QUALITY OF THE ENVIRONMENT IN SEMI-ARID REGIONS

Funded by:
The Agriculture Development Fund

January 2003
Prepared by: University of Saskatchewan

103-04306/

The Long-Term Effect of Repeated Application of Hog Manure on Soil Productivity and on the Quality of the Environment in Semi-Arid regions of Saskatchewan.

ADF Project 97000299 Res. 81BV

Abstract

Mike Grevers

High volume hog operations are planned across Saskatchewan. The general public has concerns about the disposal of large volumes of hog manure, which when applied repeatedly, may deteriorate the quality of local soils, reduce crop production and lead to pollution of the environment in general. The objectives of this study were: 1) to determine the long-term effect of repeated applications of hog manure on soil quality and on crop production in the Brown and Dark Brown soil zones, 2) to identify soil types most suitable for the long-term application of large volumes of hog manure, and 3) to determine the effect on the environment of repeated applications of soil-applied hog manure.

Crop production increased dramatically following a single application of hog manure at four farm cooperator sites located in the Brown and Dark Brown Soil Zones. There was little or no yield advantage in applying hog manure in excess of 7,500 gallons per acre (~200 lbs of N per acre). Repeated applications of manure (2x, 3x, or 4x) in subsequent years did not result in any yield advantage, except for increasing plant biomass and protein content. Applying hog manure once every 4 years appeared optimum, except for the sandy-loam textured soils, where applying hog manure once every 3 years was optimum. Poor soil moisture reserves may have limited the crop response to manure application.

Repeated applications of hog manure increased soil nitrogen levels substantially, because the rate of application of nitrogen in the manure far exceeded the plant uptake of N. The plant available N consisted of primarily nitrate-nitrogen. There was significant leaching of nitrate below the root zone (>60 cm) on sandy-loam-textured soils, due to the large pore sizes. There was also some deep leaching on a clay-textured soil, where deep surface cracks had developed in a dry year. There was no significant leaching of nitrate below the root zone (>60 cm) at a second clay-textured soil, which was not subject to surface crack formation in dry years.

Nitrous oxide (N_2O) emissions from soils treated with a single application of hog manure between 5,000 and 15,000 gallons per acre were low. However, there is a potential for higher levels of N_2O emission on fields where repeated applications of hog manure have resulted in high surface soil nitrate-nitrogen levels.

Single applications of hog manure had little or no effect on soil structure. However repeated applications of hog manure improved soil structure on the coarse-textured sandy loam soils, and caused soil structure deterioration on the clay-textured soils, which is attributable to the increased soil sodium content from the hog manure. High rates of annual hog manure applications resulted in

slight surface salinization at 3 of the 4 sites, and also in slightly increased soil sodicity of the clay-textured soils.

The result indicate that hog manure should be applied as follows:

a) Clay-textured soils: once every 4 years (or possibly once every 3 years under optimum soil moisture conditions), at approximately 6,000 gallons per acre (between 150 to 200 lbs of N/acre)
b) Sandy-loam textured soils and irrigated sandy-loam textured soils: once every 3 - 4 years at approximately 5,000 gallons per acre (150 lbs/N per acre).

The environmental effect in terms of leaching potential of nitrate is minimal on clay-textured soils, but may be significant following repeated applications of hog manure on coarse-textured (sandy loam) soils.

Future research. Additional research should be done to investigate the longer-term effects of hog manure application, beyond 4 years, especially in regards to the effect on soil physical and chemical properties. The above recommendations do not include a 5^{th} or a 6^{th} year and were based on 2 out 4 very dry growing seasons. The frequency of applications of hog manure under different crop rotations and soil-moisture regimes that include a 5^{th}, 6^{th}, 7^{th} year etc. needs to be studied to further expand the above recommendations.

The Long-Term Effect of Repeated Application of Hog Manure on Soil Productivity and on the Quality of the Environment in Semi-Arid regions of Saskatchewan.

ADF Project 97000299 Res. 81BV

Executive Summary

Mike Grevers

Introduction. Hog production in Saskatchewan is expected to increase to over 3 million hogs by the year 2005, which is triple the current production. High volume hog operations are planned across Saskatchewan; however, concerns about the disposal of large volumes of hog manure have resulted in some communities objecting to the establishment of these operations in their area. Manure applied to the soil is a generally accepted practice for improving soil fertility and for improving soil quality. In general, manure has been found to increase soil organic matter, improve soil fertility, and improve soil structure. Repeated applications of high volumes of manure, however, have led to concerns regarding the possibility of exceeding the capacity of the soil-plant system to absorb and re-cycle the nutrients supplied through the manure. Hog manure contains significant quantities of plant nutrients such as nitrogen, and large volumes of soil-applied hog manure may result in excessive levels of nitrate-nitrogen in the soil and possible groundwater contamination by nitrate leaching. Furthermore, hog manure contains salts such as sodium, and small quantities of heavy metals such as cadmium.

Project objectives. The long-term impact of hog manure applications on the quality of the soil and that of the environment is not known. For optimal application rates of hog manure in Saskatchewan, improved knowledge is essential regarding the long-term effect of hog manure application on salinity, acidity, soil density, aggregation, soil strength, crop quality and on crop production. Furthermore, the influence of hog manure on environmental quality, such as heavy metal contamination and nitrate pollution is not clear. Projects to address these issues are currently underway in the Black soil zone. However, information is also needed on manure effects in the drier Dark Brown and Brown soil zones. The objectives of this study were: 1) to determine the long-term effect of repeated applications of hog manure on soil quality and on crop production in the Brown and Dark Brown soil zones, 2) to identify soil types most suitable for the long-term application of large volumes of hog manure, and 3) to determine the effect on the environment of repeated applications of soil-applied hog manure.

Project design and methodology. A total of four sites were established in consultation with staff from the P.F.R.A. and from the Quadra Group. Two sites were located in the Brown soil zone and two sites were located in the Dark Brown soil zone, one of the four sites was an irrigated site. The Riverhurst sites involve coarse textured soils, sandy loams, and the Beechy and Plenty sites involve fine-textured soils. It is important to note that the surface horizon (0-10 cm) of the Plenty site has a clay-loam texture, and that of the Beechy site has a clay texture. The Beechy soil showed much more shrink-swell behavior than the Plenty soil, which resulted in numerous deep cracks during the late summer months in 2001 and again in 2002.

The details of the experimental design were as follows: a) four sites (one irrigated site), b) three replicated blocks at each of the sites, c) five levels of hog manure/fertilizer application rates, and six levels of repeated application rates (from one single application to four consecutive applications). The hog manure was applied either by using truck-mounted applicators, or drag-hose systems. The rate of manure application was controlled by the speed of travel. At the Riverhurst sites rates of 0, 5,000 and 10,000 gallons per acre were applied. At the Plenty and Beechy sites, rates of 0, 6,000 and 12,000 gallons per acre were applied.

Each of the sites was surveyed extensively for uniformity using a soil auger and an EM38 (measures surface soil salinity). Soil samples were collected during each year of the project, and were analyzed for soil chemical and physical properties. Crop biomass samples were collected by square meter sampling prior to harvest. Total and grain weights were determined and the grain samples were analyzed for protein content. Nitrous oxide (N_2O), a greenhouse gas, emissions were measured in 1999 and again in 2000.

Results and Discussion. Crop production increased dramatically following a single application of hog manure at four farm cooperator sites located in the Brown and Dark Brown Soil Zones. There was little or no yield advantage in applying hog manure in excess of 7,500 gallons per acre (~200 lbs of N per acre). Repeated applications of manure (2x, 3x, or 4x) in subsequent years did not result in any yield advantage, except for increasing plant biomass and protein content. Applying hog manure once every 4 years appeared optimum, except for the sandy-loam textured soils, where applying hog manure once every 3 years was optimum. Poor soil moisture reserves may have limited the crop response to manure application.

Repeated applications of hog manure increased soil nitrogen levels substantially, because the rate of application of nitrogen in the manure far exceeded the plant uptake of N. The plant available N consisted of primarily nitrate-nitrogen. There was significant leaching of nitrate below the root zone (>60 cm) on sandy-loam-textured soils, due to the large pore sizes. There was also some deep leaching on a clay-textured soil, where deep surface cracks had developed in a dry year. There was no significant leaching of nitrate below the root zone (>60 cm) at a second clay-textured soil, which was not subject to surface crack formation in dry years.

Nitrous oxide (N_2O) emissions from soils treated with a single application of hog manure between 5,000 and 15,000 gallons per acre were low. However, there is a potential for higher levels of N_2O emission on fields where repeated applications of hog manure have resulted in high surface soil nitrate-nitrogen levels.

Single applications of hog manure had little or no effect on soil structure. However repeated applications of hog manure improved soil structure on the coarse-textured sandy loam soils, and caused soil structure deterioration on the clay-textured soils, which is attributable to the increased soil sodium content from the hog manure. High rates of annual hog manure applications resulted in slight surface salinization at 3 of the 4 sites, and also in slightly increased soil sodicity of the clay-textured soils.

Conclusions and recommendations.

Repeated applications of hog manure each year or every 2nd year did not result in yield increases in 1999, 2000, 2001, and in 2002 that were significantly greater than that of a single application in the first year. However, the repeated applications, especially at the high rate of hog manure did affect

soil structure and soil chemical conditions. On sandy-loam textured soils, the repeated applications of hog manure improved the soil structure. On clay textured soils surface crust formation became noticeable and salinity and sodicity levels were slightly increased.

The result indicate that hog manure should be applied as follows:

a) Clay-textured soils: once every 4 years (or possibly once every 3 years under optimum soil moisture conditions), at approximately 6,000 gallons per acre (between 150 to 200 lbs of N/acre)
b) Sandy-loam textured soils and irrigated sandy-loam textured soils: once every 3 - 4 years at approximately 5,000 gallons per acre (150 lbs/N per acre).

The environmental effect in terms of leaching potential of nitrate is minimal on clay-textured soils, but may be significant following repeated applications of hog manure on coarse-textured (sandy loam) soils.

Future research. Additional research should be done to investigate the longer-term effects of hog manure application, beyond 4 years, especially in regards to the effect on soil physical and chemical properties. The above recommendations do not include a 5^{th} or a 6^{th} year and were based on 2 out 4 very dry growing seasons. The frequency of applications of hog manure under different crop rotations and soil-moisture regimes that include a 5^{th}, 6^{th}, 7^{th} year etc. needs to be studied to further expand the above recommendations.

The Long-Term Effect of Repeated Application of Hog Manure on Soil Productivity and on the Quality of the Environment in Semi-Arid regions of Saskatchewan.

ADF Project 97000299 Res. 81BV

Final Report

Mike Grevers

Introduction

Hog production in Saskatchewan is expected to increase to over 3 million hogs by the year 2005, which is triple the current production. High volume hog operations are planned across Saskatchewan; however, concerns about the disposal of large volumes of hog manure have resulted in some communities objecting to the establishment of these operations in their area.

Manure applied to the soil is a generally accepted practice for improving soil fertility and for improving soil quality. In general, manure has been found to increase soil organic matter, improve soil fertility, improve soil structure (Chater and Gasser, 1970; Sommerfeldt et al. 1988), and increase crop production (Grevers and Schoenau, 1997; Sommerfeld and Chang, 1985). Repeated applications of high volumes of manure, however, have led to concerns regarding the possibility of exceeding the capacity of the soil-plant system to absorb and re-cycle the nutrients supplied through the manure. Hog manure contains significant quantities of plant nutrients such as nitrogen, and large volumes of soil-applied hog manure may result in excessive levels of nitrate-nitrogen in the soil and possible groundwater contamination by nitrate leaching. Furthermore, hog manure contains salts such as sodium, and small quantities of heavy metals such as cadmium. The general public is concerned that large volumes of hog manure, some as high as 15,000 gallons per acre, when applied repeatedly, may deteriorate the quality of local soils, reduce crop production and lead to pollution of the environment in general (Chang et al. 1990; Larson, 1991a,b).

The long-term impact of hog manure applications on the quality of the soil and that of the environment is not known. Larney et al. (1993) caution that the residual effect of long-term manure applications needs to be evaluated. For optimal application rates of hog manure in Saskatchewan, improved knowledge is essential regarding the long-term effect of hog manure application on salinity, acidity, soil density, aggregation, soil strength, crop quality and on crop production. Furthermore, the influence of hog manure on environmental quality, such as heavy metal contamination and nitrate pollution is not clear. Projects to address these issues are currently underway in the Black soil zone. However, information is also needed on manure effects in the drier Dark Brown and Brown soil zones.

The objectives of this study are: 1) to determine the long-term effect of repeated applications of hog manure on soil quality and on crop production in the Brown and Dark Brown soil zones, 2) to identify soil types most suitable for the long-term application of large volumes of hog manure, and 3) to determine the effect on the environment of repeated applications of soil-applied hog manure.

PROJECT DESIGN:

Field Study

A total of four sites were established in consultation with staff from the P.F.R.A. and from the Quadra Group. Two sites were located in the Brown soil zone and two sites were located in the Dark Brown soil zone, one of the four sites was an irrigated site. The description of the field plot locations and the general characteristics of the physical and chemical properties are shown below. The Riverhurst sites involve coarse textured soils, sandy loams, and the Beechy and Plenty sites involve fine-textured soils. It is important to note that the surface horizon (0-10 cm) of the Plenty site has a clay-loam texture, and that of the Beechy site has a clay texture. The Beechy soil showed much more shrink-swell behavior than the Plenty soil, which resulted in numerous deep cracks during the late summer months in 2001 and again in

2002. On the other hand, the surface layer at the Plenty site became powdery during extended dry periods, and crack formation ocurred below this powdery layer.

Description of field sites

Site #1 Plenty. Cooperator: Victor Hamilton. Hog Barn: Eagle Creek Hog Barn
Field Location: SW 5-33-18-W3. Soil type: Regina Association, clay to heavy clay

Site #2 Beechy. Cooperator: Robert Odermatt. Hog Barn: Beechy Hog Barn
Field Location: NW11-22-11-W3. Soil Type: Willows Association, clay to clay loam

Site #3 River Lake-Irrigated. Cooperator: Rick Loepke. Hog Barn: River Lake Hog barn
Field Location: SW20-24-5-W3. Soil type: Birsay Association, sandy loam

Site #4 River Lake-Dry-Land. Cooperator: Rick Loepke. Hog Barn: River Lake Hog barn
Field Location: SW18-24-5-W3. Soil type: Birsay Association, sandy loam

General physical and chemical characteristics of the research plots

Site	Depth	Sand	Silt	Clay	Texture	pH	EC
	cm	%	%	%			dS/m
Plenty	0-10	20.8	44.4	34.9	CL	8.3	0.6
	10-30	14.8	32.9	52.3	C	8.3	0.6
	30-60	14.0	32.1	53.9	C	8.1	2.1
Beechy	0-10	26.0	26.6	47.4	C	8.4	0.4
	10-30	31.6	21.6	46.8	C	8.4	0.4
	30-60	26.8	21.0	52.2	C	8.4	1.9
RH-irrig.	0-10	59.8	25.6	14.5	SL	8.1	0.3
	10-30	64.1	26.7	9.2	SL	8.1	0.3
	30-60	68.5	23.3	8.2	SL	8.3	0.4
RH-dryl.	0-10	57.2	26.6	16.2	SL	8.1	0.3
	10-30	74.2	13.4	12.4	SL	8.1	0.3
	30-60	57.1	24.6	18.4	SL	8.3	1.2

The experimental design was as follows (also see the diagram on next page):

Four sites (one irrigated site)

Three replicated blocks at each of the sites

Five levels of hog manure/fertilizer application rates

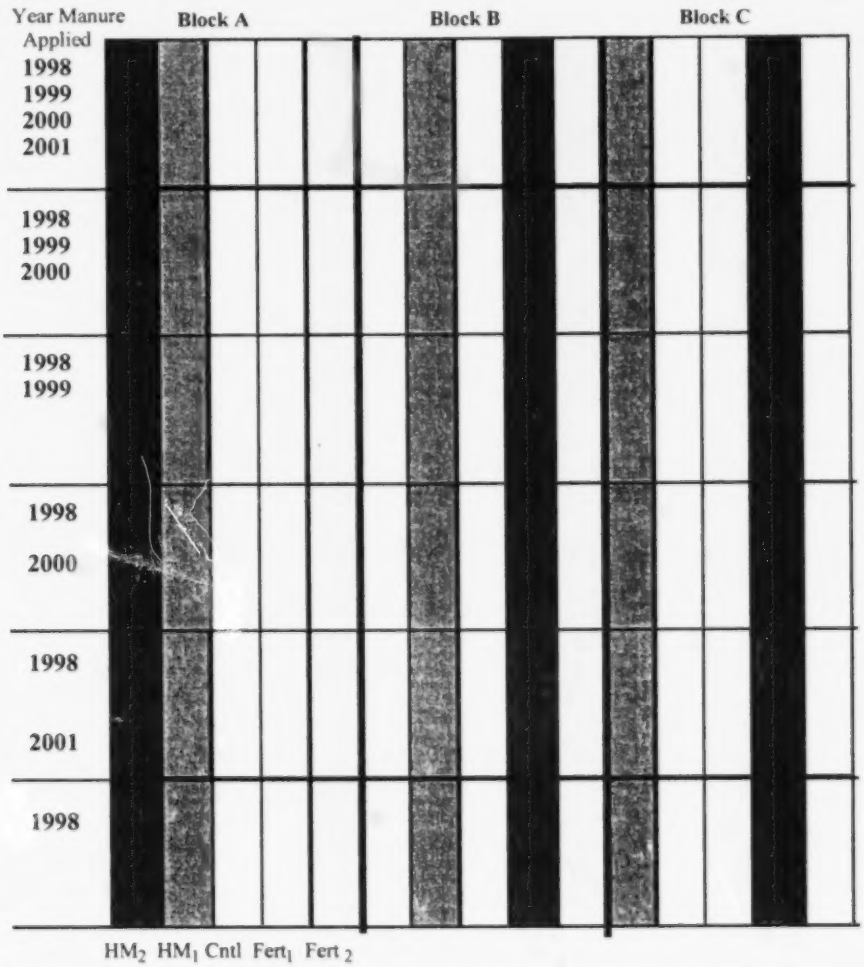
- Control (no hog manure or fertilizer)
- 5,000 gallons per acre of hog manure soil injected
- 10,000 gallons per acre of hog manure soil injected
- Low rate of fertilizer (100% of soil test recommendations for N as urea)
- High rate of fertilizer (200% of soil test recommendations for N as urea)

Six levels of repeated application rates.

- a one-time application only
- 2 successive annual applications,
- 3 successive annual applications,
- 4 successive annual applications,
- applied once every two years,
- applied once every 3 years

Identification of plot boundaries

Prior to the application of the manure ball markers were buried at a depth of 20 cm to indicate the locations of all plots. Ball markers can be detected at distances of up to 1 m and at depths of up to 1 m. Ball markers were placed at each outside corner and at the middle of the plots. Following seeding and prior to harvest operations, flags and/or stakes were used to indicate plot boundaries. These were removed prior to field tillage, seeding and harvest operations.



Manure Treatments: HM_1: 5,000 gallons per acre of Hog Manure
HM_2: 10,000 gallons per acre of Hog manure
Cntl: Control: no Hog Manure and no Fertilizer
$Fert_1$: Chemical Fertilizer at low rate
$Fert_2$: Chemical Fertilizer at high rate

Rotations: years indicate when manure is applied

Plot dimensions: Main Plot: 300' x 600' = 180,000 ft^2 = 4.1 acres
Replicate Blocks: 3 replicate blocks. Each block consists of 5 manure/fertilizer treatments x 6 annual applications.
Sub-plots: width 15 feet wide + 5 foot border (20 ft for plot width)
length: 75 feet + 25 feet border for a total of 100 feet

Application of liquid hog manure
The actual application rates in gallons per acre of hog manure were adjusted to the soil type, and were applied either in the fall or in the spring prior to a growing season

Site	Fall/Spring & year	Low rate	High Rate	Method
Plenty	Fall 1998	5,500	13,500	Truck
	Fall 1999	6,000	12,000	Truck
	Fall 2000	6,000	12,000	Truck
	Fall 2001	6,000	12,000	Truck
Beechy	Fall 1998	7,560	15,250	Truck
	Fall 1999	6,000	12,000	Truck
	Fall 2000	6,000	12,000	Truck
	Fall 2001*	0	0	
Riverhurst-dryland	Spring 1999	5,000	10,000	Drag-hose
	Spring 2000	5,000	10,000	Truck
	Fall 2000	5,000	10,000	Truck
	Fall 2001	5,000	10,000	Truck
Riverhurst-irrigated	Spring 1999	5,000	10,000	Drag-hose
	Spring 2000	5,000	10,000	Truck
	Fall 2000	5,000	10,000	Truck
	Fall 2001	5,000	10,000	Truck

* No manure was applied at Beechy. Farm Cooperator did not give permission.

The hog manure was applied either by using truck-mounted applicators (Fig. 1), or drag-hose systems (Fig. 2 and Fig. 3). The rate of manure application was controlled by the speed of travel.

The truck-mounted applicators essentially are containers trucks with a capacity to hold up to ~6,000 gallons of manure. These trucks would fill up at the lagoon and be emptied on the field. One or two truck loads were sufficient to supply all the manure for a research plot. However, in order to empty a lagoon, the trucks had to make a large number of trips, causing concern by the farm cooperators that these trucks would cause soils compaction.

A drag-hose system was also used, where manure is pumped from the lagoon into a long hose (up to 2 km) attached to a cultivator. The manure is injected behind the cultivator shanks. An obvious advantage of this system is the minimum amount of travel between the lagoon and the field. This system works well on large fields. However, it became difficult to apply manure on small research plots, since the pump at the lagoon had to be turned off frequently to apply the correct amount of manure to each of the small plots.

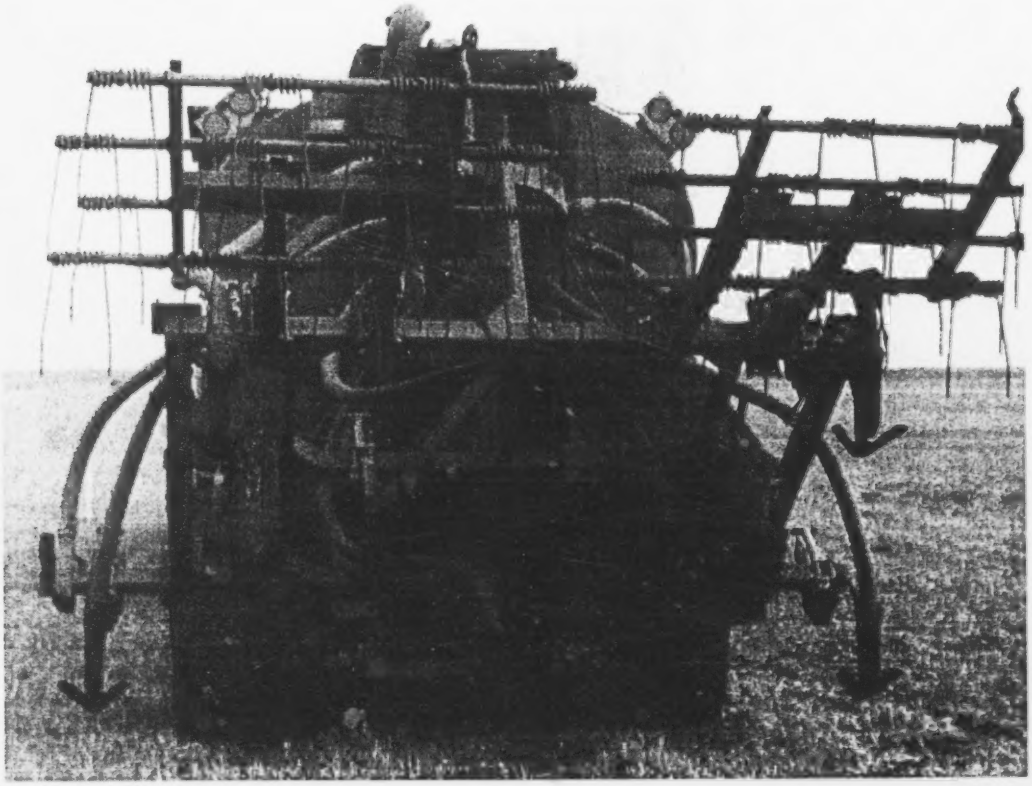


Fig. 1. Truck-mounted system for soil injecting liquid hog manure

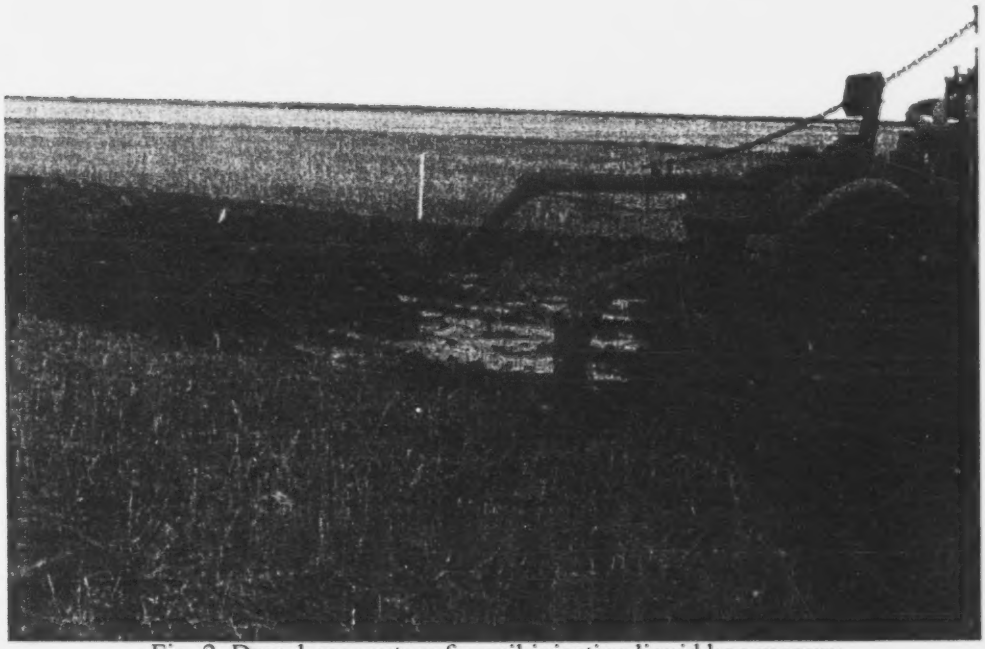
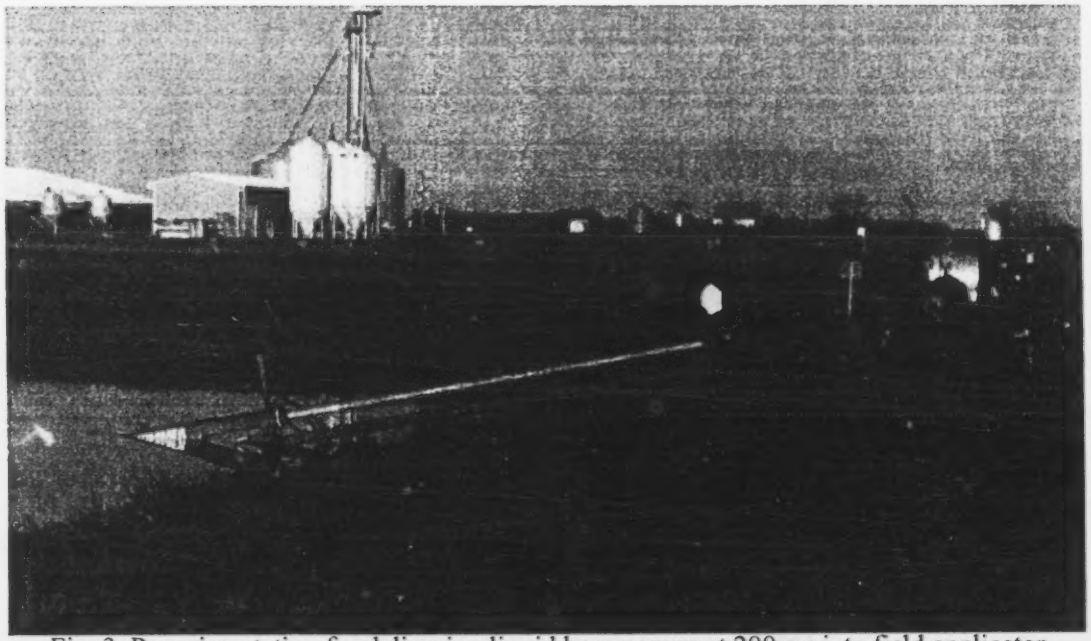


Fig. 2. Drag-hose system for soil injecting liquid hog manure



- Fig. 3. Pumping station for delivering liquid hog manure at 200 p.s.i. to field applicator

- Fig. 4. Manure sampling

- Fig. 5. Field plot sign at Plenty

The amount of soil disturbance and flattening of stubble depended on the type and quality of the injector knifes, and on the rate of application (fig. 4). Well-worn cultivator shanks caused considerable soil disturbance. Low application rates, meant slow travel speeds, which also resulted in a higher degree of disturbance and the flattening of stubble.

The depth of application was set at 15 cm, however the actual depth (measured in the field) averaged around 12 cm.

- Fig. 6. Soil injected with liquid hog manure at Plenty, SK

Analysis of hog manure

During the application of the hog manure samples were collected from the applicator. The samples were transported to the Univ. of Sask. where they were stored at 4° C and analyzed for chemical characteristics.

Details of the nutrients contained in the hog manure are shown in Appendix I. Also shown in Appendix I, is the estimated amount of nutrients applied during 4 annual applications at the high rate of application for each site. The amount of plant available N levels ranged from 1120 to 1672 kg/ha, and the total N levels ranged from 1382 to 2112 kg/ha. It is also important to note that a considerable amount of salt was added; for example at the Plenty site 436 kg/ha of Na-salts were added.

Soil analysis
Each of the sites was surveyed extensively for uniformity using a soil auger and an EM38 (measures surface soil salinity). Soil samples were collected from the top 60 cm, and transported to the University of Saskatchewan where they were dried, ground and analyzed for soil chemical and physical properties. In the spring, soil water content, soil strength and soil density were sampled in the field. In the final year of the project soil samples were collected from below the root zone and analyzed for nitrates etc.

Plant and yield analysis.
Crop biomass samples were collected by square meter sampling prior to harvest. The samples were transported to the Univ. of Sask., where they were dried, weighed, and threshed. Total and grain weights were determined and the grain samples were analyzed for protein content.

Growth Chamber study
Surface soil samples (0-15 cm) were collected from the control plots (no manure applied) and transported to the University of Saskatchewan, where they were dried and ground to pass a 2-mm sieve. Growth chamber studies were carried out under controlled temperature, humidity and day length conditions. Six rates of hog manure (0, 3,000, 6,000, 9,000, 12,000, and 15,000 gallons per acre) and 4 rates of fertilizer (50%, 100, 150 and 200% of fertilizer N & P recommendations) were applied to soil containers. The containers were seeded to a cereal and a Canola crop and incubated at room temperature for 12 weeks. Crop yield and plant nutrient uptake were determined. Soil pH, salinity and sodicity were measured during the experiment. The treatments were repeated as in the field trials using the same soil containers, and were incubated and monitored for soil chemical and physical properties. At the end of the incubation period, soil strength (Modulus of Rupture (Richards, 1953), soil aggregation, soil density and soil shrinkage potential (COLE index) were measured.

M.Sc. Thesis project on Nitrous Oxide gas emission from manure applications
Ms. Grace Dauk, a graduate student (M.Sc. degree), worked on a joint project with Dr. Richard Farrell on the nitrogen balance of hog manure application to the soil. Specifically the title of Ms. Dauk's thesis project was: "A Comparison of Nitrous Oxide Flux in a Clay and in a Sandy Soil in the Brown Soil Zone of Saskatchewan". The fundamental objective of this research project was to quantify the effects of applied liquid hog manure on the soil surface nitrous oxide emissions from typical farm fields in Saskatchewan.

Ambient fluxes of N_2O from the research plots were collected using closed chambers, consisting of stainless steel chambers coated with polyurethane foam insulation and covered with aluminum foil to minimize temperature fluctuations due to internal heating. Gas samples were collected during the 1999 growing season, and again in the spring of 2000. Gas samples were analyzed by gas chromatography.

Field crops
The plots were seeded to the following crops:

Site	2002	2001	2000	1999
Plenty	Crop failure	Spr. wheat	Chick Peas	Spr. wheat
Beechy	Chick pea	Spr. wheat	Lentils	Durum
Riverhurst dry-land	Oats	Summerfallow	Barley	Canola
Riverhurst Irrigated	Crop failure	Barley	Barley	Canola

RESULTS AND DISCUSSION

Crop production

The effect of hog manure application and that of urea fertilizer on grain yields during each of the four years of the study are shown in Tables 1, 2, 3, and 4. The details of the crop yields measured in 2002, 2001, 2000, and in 1999 are shown in Appendixes II, III, IV, and V. Drought conditions and grasshopper problems caused low yields and subsequent limited yield responses to the manure applications in 2001 and again in 2002. One research plot had to be summerfallowed in 2001, and two research plots ended up in complete crop failure in 2002.

The analysis of the yield data must consider the following

a) At the Beechy site, the plot was seeded to lentils in 2000. This crop obviously will not benefit from the applied manure and fertilizer to same extend as do cereals. Similarly, in 2002 chickpeas were grown.
b) At the Plenty site, the 2000 and 2001 crops suffered from drought, and there was a total crop failure in 2002.
c) At the Riverhurst-Irrigated site, the plot was seeded to beans in 1999, which resulted in a limited response to hog manure and to fertilizer N in the following year. In 2002, the crop was badly damaged by grasshoppers and no yields could be measured.
d) At the Rverhurst-dryland site, the plot had to be summer fallowed in 2001 due to insufficient soil –moisture reserves.

Discussion and conclusions of the yield results

1. A single application of a low rate of hog manure improved crop production for up to three years (exceptions are Beechy and Riverhurst-dryland, which are explained above).
2. There is little or no yield advantage in applying hog manure at the higher rate (except for the Plenty site where there was a substantial residual effect in year 3 for the high rate of application).
3. The more impoverished sandy soils benefited more from the manure application that the more fertile clay soils (for the Riverhurst-dryland, the yield increases were 8 fold in year 1, and for the Riverhurst-dryland, there was a large residual effect in year 3 following a single application in year 1).
4. Repeated applications of manure (2x, 3x, or 4x) did not result in any yield advantage, and in fact resulted in a yield disadvantage at two sites compared to a single application at the low rate. However, poor soil moisture reserves may have limited crop response to manure application
5. The yield increases due to the application of urea fertilizer, either at the 1x or 2x field test recommendations resulted in modest yield increases that were substantially below that of the manure applications at the single application of a low rate.
6. The hog manure increased the percentage of protein in the crop by up to 5% on the heavy-textured Plenty and Beechy sites, and between 5 and 8% on the sandy loam Riverhurst sites. Urea fertilizer increased the percentage of protein in the crop by up to 3% on the heavy-textured Plenty and Beechy sites, and between 3 and 5% on the sandy loam Riverhurst sites.

Soil fertility

The effect of hog manure application on plant available nitrogen levels are shows in Tables 5-8, and in Figures 1 and 2. For the Beechy and Plenty sites the N content of the hog manure was on average 30 kg/ha per 1,000 gallons of manure. The rates of 6,000 and 12,000 gallons per acre therefore added 180 and 360 kg/ha of N, most of which was immediately available as NH_4-N. These application rates exceeded the crop removal considerably, especially considering the effect of dry soil conditions on

slightly higher. Application rates of 5,000 and 10,000 g.p.a. added 340 and 680 kg/ha of N. The total amount of nitrogen added to the soils from 4 annual applications at the high rates, ranged from 1,382 to 2,112 kg/ha (Appendix I).

Soil N levels increased with manure application. At the Plenty site, soil N levels in the 0-60 cm depth reached 1,209 kg/ha after three consecutive applications at the high rate. At the other sites the accumulated soil N levels were lower; however, there was a considerable amount of N unaccounted for at these sites. Fig. 2 shows the amount of N that was lost either through leaching (beyond 120 cm depth) or due to volatilization and/or denitrification. At the Plenty site, most of the N was accounted for, except when manure was applied at high rates for 4 consecutive years. At the Beechy site an average of 250 kg/ha of N was unaccounted for. At the Riverhurst sites, the amount of unaccounted for N increased with the frequency of application from less than 200 kg/ha to up to 600 kg/ha.

The distribution of plant available N levels with depth for the high application rates following one, two, three and four annual applications are shown in Figures 3, 4, 5, and 6. At the Plenty site, the increased soil N levels is contained in the top 60 cm. However, at the Beechy site, increased soil N levels also existed in the 60-90 and in the 90-120 cm depth. At the Riverhurst sites, the greatest concentration of soil N occurred in the 30-60 cm depth. The results suggest that the heavy textured soil at Plenty results in minimal loss of N. The soil at Beechy which is subjected to significant crack formation (more so than the Plenty clay soil), resulted in a considerable amount of N leaching. The sandy soils at Riverhurst resulted in a large amount of N leaching.

Discussion and conclusions of the soil nitrogen results

1. The repeated applications of hog manure, especially at the high rate, exceeded the plant uptake of N resulted in high levels of accumulated plant available soil N.
2. The plant available N consisted of primarily nitrate-nitrogen
3. There was significant leaching of nitrate below the root zone (>60 cm) at three sites
    a. at the Riverhurst sites, due to the large pore sizes on these sandy loam-textured soils
    b. at the Beechy site, due to the crack formation on this clay textured soil
4. There was no significant leaching of nitrate below the root zone (>60 cm) at the clay-textured Plenty site, which did not show crack formation on the surface.

Gaseous losses of N, nitrous oxide emissions.

Nitrous oxide is one of the three principal radiatively active trace gases in the earth's atmosphere (the other being CO_2 and CH_4). Together, these trace gases influence the earth's radiation balance, making the planet habitable, while influencing global climate. There is a potential of increased N_2O emissions due to hog manure application. Nitrous oxide gases can be produced either during nitrification or during denitrification:

a) Nitrification

$$NH_4^+ \Rightarrow NH_2OH \Rightarrow H_2N_2O_2 + \mathbf{N_2O}^{\uparrow} \Rightarrow NO_2^- \Rightarrow NO_3^-$$

b) Denitrification

$$NO_3^- \Rightarrow NO_2^- \Rightarrow NO \Rightarrow \mathbf{N_2O}^{\uparrow} \Rightarrow N_2$$

Urine contained in hog manure is quickly hydrolyzed to NH_4^+, thereby creating a substrate for nitrification. The nitrification process under the relatively dry conditions in the Brown and Dark Brown Soil Zones, proceeds rapidly converting NH_4-N to NO_3-N. Hog manure is injected into narrow

bands that are moist (approximately 1 cm of water is applied per hectare during manure application at 8,000 g.p.a.), and contain high levels of water soluble or readily minerizable carbon, which is stimulates the activity of the denitrifying microorganisms. Furthermore, the bacteria responsible for denitrification are facultative anaerobes, and high soil moisture regimes favours their activity. Nitrous oxide emission following the first application of hog manure are shown below.

Treatment	Beechy	Riverhurst-dryland
	---------- kg/ha of N_2O-N per year	
Control	0.020	0.015
Hog Manure- low rate	0.115	0.758
Hog Manure- high rate	0.221	1.231

There can be considerable fluctuations in N_2O emissions, due to the effect of changing temperature and moisture regimes during the growing season. In general N_2O fluxes for cultivated field range between 2.5 and 3.0 kg/ha of N_2O-N per year, under cultivated field conditions and approximately 1 kg/ha of N_2O-N per year under uncultivated conditions (Bouwman,1990). In light of the above the values presented above are relatively small.

There is however, the potential for much higher nitrous oxide emissions from the soil and that of denitrification in general in the spring of 2003, under warm and moist soil conditions. The nitrate-N levels that were measured in the fall of 2002, are much higher than those that existed when the above N_2O measurements were taken.

Soil structure.

The application of manure in general has been shown to affect soil structure, in terms of reduced soil bulk density, increased porosity (macro-porosity) and increased soil aggregation. However, the above primarily involves the application of cattle manure. Liquid hog manure contains only about 5% solids, and the remaining liquid portion (~95%) has a high concentration of salts, in particular sodium salts. The effect of long-term repeated applications of hog manure on soil physical properties is therefore expected to be quite different than that of cattle manure.

The analysis of soil structure parameters is presented in Tables 9 and 10, and includes the following: soil bulk density, soil-water infiltration, saturated hydraulic conductivity, and aggregate size distribution.

Discussion and conclusions of the soil physical properties results:

1. There was no effect of the annual applications of either hog manure or of urea fertilizer on soil bulk density. This finding is consistent with other reports. Hog manure primarily consists of water and therefore is not expected to decrease soil bulk density to the extent that cattle manure does.
2. The soil strength data indicates that the surface layer at the Plenty site has increased in soil strength (penetrometer) as a result of annual hog manure applications. This can be explained by increased level of sodium (SAR) at this depth (Table 11). There was no effect on soil strength (penetrometer or shear vane) at the other sites.
3. Cumulative water infiltration. There were no treatment effects on soil-water infiltration. This measurement is effected by spatial variability of surface soil conditions, especially with respect to crack formation. At the Beechy site, cracks could be avoided in the determination of the sampling locations. However, at the Plenty site, the cracks were not visible at the surface (they were covered

by a 5-cm layer of loose soil material), and these "buried" cracks likely masked potential treatment effects.

4. Saturated hydraulic conductivity. There were no significant differences in saturated hydraulic conductivity (K-sat) in any of the plots. However, there was a trend of increased K-sat in the hog manure and urea fertilizer plots compared to the control plots. This can be explained by the increased biomass production achieved in these sandy-loam soils by these treatments.
5. Soil aggregate size distribution (mean-weight-diameter). There were no treatment effects on soil aggregation of the soil aggregates at Beechy and at the Riverhurst sites. This is consistent with other reports. Hog manure primarily consists of water and therefore is not expected to affect soil aggregation to the extent that cattle manure does. However, at the Plenty site, soil aggregation decreased in the hog manure plots. This can be explained by increased level of sodium (SAR) at this depth (Table 11).
6. The above findings indicate a gradual effect of improved soil structure on the coarse-textured sandy loam soils at Riverhurst following repeated high applications of hog manure. The results also indicate that on the heavy-textured clay soils at Plenty, annual applications of high rates of hog manure causes soil structure deterioration, which is attributable to the increased soil sodium that was added with the manure. The heavy-textured clay soils at Beechy, did not suffer soil structure deterioration to the same extent as soil at the Plenty site. At Beechy, there is a greater downward movement of soluble material as indicated by the soil nitrogen data.

Soil chemistry

Hog manure adds a limited amount of organic matter and considerable amounts of salts to the soil, and it also results in increased microbial activity. Large amounts of NH_4-N are added, which when nitrified to NO_3-N result in the lowering of soil pH. It is therefore expected that soil chemical conditions of the surface may change following long-term applications of the manure

The analysis of soil chemical parameters is presented in Table 11, and includes the following: soil reaction (pH), soil salinity (EC), and soil sodicity (SAR).

Discussion and conclusions of the soil chemical properties' results:

1. The hog manure applications had only a small effect on soil pH. At the Plenty site, soil pH was reduced from 7.7 to 7.4
2. High rates of annual hog manure applications resulted in surface salinization at 3 of the 4 sites. At the Plenty, Beechy and at Riverhurst-irrigated sites, surface soil salinity values increased to that of slighltly saline to moderately saline levels. There was no effect on soil salinity at the Riverhurst-dryland site.
3. High rates of annual hog manure applications increased soil sodicity at the Plenty site, and there was a trend in the data at the Beechy site, also suggesting increased soil sodicity. There was no effect on soil sodicity at the Riverhurst sites. The heavy-textured clay soils are more prone to sodification due to limited leaching of electrolytes (salts) in these soils, particularly for that of sodium salts.
4. The above results are consistent with the results of the growth chamber study (Appendix VI), which showed that repeated applications of large volumes of hog manure have the potential for increasing both soil salinity and soil sodicity

References:

Barzegar, A.R., J.M. Oades and P. Rengasamy. 1996. Soil structure degradation and mellowing of compacted soils by saline sodic solutions. Soil Sci. Am. J. 60: 583-588.

Cass, A. and M.E. Sumner. 1982. Soil pore structural stability and irrigation water quality: II. Sodium Stability Data. Soil Sci. Am. J. 46: 507-512.Chang, C., T.G. Sommerfeldt and T. Entz. 1990. Rates of soil chemical changes with eleven annual applications of cattle feedlot manure. Can. J. Soil Sci. 70: 673-681.

Chang, C., T.G. Sommerfeldt and T. Entz. 1990. Rates of soil chemical changes with eleven annual applications of cattle feedlot manure. Can. J. Soil Sci. 70: 673-681.

Charles, J.L. 1999. Soil and Crop Response to Hog and Cattle Manure Additions in East Central Saskatchewan. Ph.D. Thesis . Univ. of Saskatchewan, Saskatoon, SK 150 pp.

Cochrane, H.R., G. Scholz, and A.M.E. Van Vreeswyk. 1994. Sodic Soils in Western Australia. Aust. J. Soil Res. 32: 359-388.

Crescimanno, G, M. Iovino and G. Provenzano. 1995. Influence of salinity and sodicity on soil structural and hydraulic characteristics. Soil Sci. Am. J. 59: 1701-1708.

Curtin, D., H. Steppuhn and F. Selles. 1994. Effects of magnesium on cation selectivity and structural stability of sodic soils. Soil Sci. Am. J. 58: 730-737

Grevers, M.C.J. 1998 Amending and Supplying Nutrients to Poorly Drained Soils with Hog Manure, Using a Low Odour and Low Cost Method Final research report. Saskatchewan Agriculture Development Fund. Regina, SK, Canada

Grevers, M.C.J. and E. de Jong. 1993. Soil structure and crop yield over a 5-year period following subsoiling Solonetzic and Chernozemic soils in Saskatchewan. Can. J. Soil Sci. 73: 81-91.

Grevers, M.C.J. and J.J. Schoenau, 1997. Improving soil quality by injecting liquid hog manure and elemental sulphur. Proc. 1997 Soils & Crops Workshop, University of Saskatchewan, Saskatoon, SK.

Larney, F.J., G. Chang, and B.S. Freese. 1993. Manure application under dryland and irrigated conditions. Proc. and Recomm. for manure Management Workshop, Saskatoon, SK. December 8 & 9, 1993

Larson, B.G. 1991. Saskatchewan Pork Industry Manure Management Recommendations. Quadra Management Services Ltd.

Larson, B.G. 1991. Saskatchewan Pork Industry Manure Management Recommendations. Quadra Management Services Ltd.

Rengasamy, P. and K.A.Olsson. 1991. Sodicity and soil structure. Aust. J. Soil Res. 29: 935-952Rengasamy P. and K.A. Olsson, 1995. Irrigation ad sodicity: An overview. *PP* 195-204 In Australian Sodic Soils Distribution, properties and Management (Naidu, Sumner and Rengasamy Ed's) C.S.I.R.O. Publ. 351 pp.

So, H.B. and L.A.G. Aylmore. 1995. The effects of sodicity on soil physical behaviour. Pp: 71:79. *In* (R.Naidu, M.E. Sumner and P. Rengasamy Ed.'s) Australian Sodic Soils, distribution, properties and management. CSIRO Publ., East Melbourne, Victoria, Australia.

Sommerfeldt, T.C., C. Chang, and T. Entz. 1988. Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. Soil Sci. Soc. Am. J. 52: 1668-1672.

Sommerfeldt, T.C., C. Chang. 1985, Changes in soil properties under annual applications of cattle feedlot manure. Soil Sci. Soc. Am. J. 51: 7-9.

Stonehouse, H.B. 1991. Solonetzic Soils; Their Nature And Distribution In Saskatchewan. PP: 537-544 *IN* Proc. 1991 Soil and Crops Workshop. University of Saskatchewan, Saskatoon, SK.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. USDA Handbook 60. U.S. Gov. Print. Office, Washington, DC.

Table 1. Grain yields at the Beechy site during each year of the project.

Treatment	1999 Durum	2000 Lentil	2001 Durum	2002 Chickpea
X 0 0 0	kg/ha	kg/ha	kg/ha	kg/ha
Control	1617 *b*	2118 *abcd*	528	1763*b*
Low rate of hog manure	3008 *a*	2222 *ab*	543	2523*a*
High rate of hog manure	2965 *a*	1851 *cd*	464	2191*ab*
Low rate of urea	2296 *ab*	2372 *a*	603	1943 *ab*
High rate of urea	2269 *ab*	1829 *d*	681	2017*ab*
X 0 0 X				
Control	1617 *b*	2118 *abcd*	528	2126 *ab*
Low rate of hog manure	3008 *a*	2222 *ab*	543	1834 *ab*
High rate of hog manure	2965 *a*	1851 *cd*	464	2714 *a*
Low rate of urea	2296 *ab*	2372 *a*	464	2139 *ab*
High rate of urea	2269 *ab*	1829 *d*	406	1756 *b*
X 0 X 0				
Control	1617 *b*	2118 *abcd*	528	2113 *ab*
Low rate of hog manure	3008 *a*	2222 *ab*	413	2009 *ab*
High rate of hog manure	2965 *a*	1851 *cd*	387	1828 *ab*
Low rate of urea	2296 *ab*	2372 *a*	500	2302 *ab*
High rate of urea	2269 *ab*	1829 *d*	510	2118 *ab*
X X 0 0				
Control	1617 *b*	1911 *bcd*	528	2100 *ab*
Low rate of hog manure	3008 *a*	2218 *abc*	495	2653 *a*
High rate of hog manure	2965 *a*	1869 *bcd*	467	2329 *ab*
Low rate of urea	2296 *ab*	2089 *abcd*	472	2355*ab*
High rate of urea	2269 *ab*	1932 *ef*	480	1915 *ab*
X X X 0				
Control	1617 *b*	1911 *bcd*	528	2466 *a*
Low rate of hog manure	3008 *a*	2218 *abc*	405	2057 *ab*
High rate of hog manure	2965 *a*	1869 *bcd*	429	1519 *b*
Low rate of urea	2296 *ab*	2089 *abcd*	464	2100 *ab*
High rate of urea	2269 *ab*	1932 *ef*	406	1728 *ab*
X X X X				
Control	1617 *b*	1911 *bcd*	528	2173*ab*
Low rate of hog manure	3008 *a*	2218 *abc*	405	1632*b*
High rate of hog manure	2965 *a*	1869 *bcd*	429	2044 *ab*
Low rate of urea	2296 *ab*	2089 *abcd*	464	2300 *ab*
High rate of urea	2269 *ab*	1932 *ef*	406	1964 *ab*

Treatment legend: X X X X indicate year of application

Means followed by the same letter are not significantly different at *P 0.05*.

Table 2. Grain yields at the Plenty site during each year of the project.

Treatment	1999 Wheat	2000 Canary S.	2001 Wheat	2002 No crop
X 0 0 0	kg/ha	kg/ha	kg/ha	kg/ha
Control	1607 *d*	676 *bc*	798 *cd*	
Low rate of hog manure	4488 *a*	873 *a*	828 *bcd*	
High rate of hog manure	4514 *a*	920 *a*	1114 *a*	
Low rate of urea	3072 *c*	601 *bc*	727 *b*	
High rate of urea	4023 *b*	582 *bc*	692 *b*	
X 0 0 X				
Control	1607 *d*	676 *bc*	798 *cd*	
Low rate of hog manure	4488 *a*	873 *a*	828 *bcd*	
High rate of hog manure	4514 *a*	920 *a*	1114 *a*	
Low rate of urea	3072 *c*	601 *bc*	727 *b*	
High rate of urea	4023 *b*	582 *bc*	692 *b*	
X 0 X 0				
Control	1607 *d*	676 *bc*	798 *cd*	
Low rate of hog manure	4488 *a*	873 *a*	808 *cd*	
High rate of hog manure	4514 *a*	920 *a*	952 *abc*	
Low rate of urea	3072 *c*	601 *bc*	920 *abc*	
High rate of urea	4023 *b*	582 *bc*	882 *bcd*	
X X 0 0				
Control	1607 *d*	554 *c*	798 *cd*	
Low rate of hog manure	4488 *a*	591 *bc*	810 *cd*	
High rate of hog manure	4514 *a*	587 *bc*	1038 *ab*	
Low rate of urea	3072 *c*	634 *bc*	635 *b*	
High rate of urea	4023 *b*	702 *b*	728 *b*	
X X X 0				
Control	1607 *d*	554 *c*	798 *cd*	
Low rate of hog manure	4488 *a*	591 *bc*	840 *bcd*	
High rate of hog manure	4514 *a*	587 *bc*	1081 *a*	
Low rate of urea	3072 *c*	634 *bc*	718 *b*	
High rate of urea	4023 *b*	702 *b*	699 *b*	
X X X X				
Control	1607 *d*	554 *c*	798 *cd*	
Low rate of hog manure	4488 *a*	591 *bc*	840 *bcd*	
High rate of hog manure	4514 *a*	587 *bc*	1081 *a*	
Low rate of urea	3072 *c*	634 *bc*	718 *b*	
High rate of urea	4023 *b*	702 *b*	699 *b*	

Treatment legend: X X X X indicate year of application
Means followed by the same letter are not significantly different at *P 0.05*.

Table 3. Grain yields at the Riverhurst-irrigated site during each year of the project.

Treatment	1999 Beans	2000 Barley	2001 Barley	2002 No crop
X 0 0 0	kg/ha	kg/ha	kg/ha	kg/ha
Control	2166 *b*	3508 *ab*	1903 *c*	
Low rate of hog manure	2997 *a*	3658 *a*	3170 *a*	
High rate of hog manure	2855 *a*	3591 *ab*	3522 *a*	
Low rate of urea	2357 *b*	3669 *a*	2165 *b*	
High rate of urea	2252 *b*	3431 *abc*	2100 *b*	
X 0 0 X				
Control	2166 *b*	3508 *ab*	1903 *c*	
Low rate of hog manure	2997 *a*	3658 *a*	3170 *a*	
High rate of hog manure	2855 *a*	3591 *ab*	3522 *a*	
Low rate of urea	2357 *b*	3669 *a*	2165 *b*	
High rate of urea	2252 *b*	3431 *abc*	2100 *b*	
X 0 X 0				
Control	2166 *b*	3508 *ab*	1613 *c*	
Low rate of hog manure	2997 *a*	3658 *a*	3177 *a*	
High rate of hog manure	2855 *a*	3591 *ab*	3507 *a*	
Low rate of urea	2357 *b*	3669 *a*	2413 *b*	
High rate of urea	2252 *b*	3431 *abc*	2423 *b*	
X X 0 0				
Control	2166 *b*	3372 *abc*	1993 *c*	
Low rate of hog manure	2997 *a*	2918 *cd*	3167 *a*	
High rate of hog manure	2855 *a*	3052 *bc*	3637 *a*	
Low rate of urea	3072 *c*	3077 *bc*	2377 *c*	
High rate of urea	2252 *b*	2463 *d*	2407 *c*	
X X X 0				
Control	2166 *b*	3372 *abc*	1952 *c*	
Low rate of hog manure	2997 *a*	2918 *cd*	3292 *a*	
High rate of hog manure	2855 *a*	3052 *bc*	3602 *a*	
Low rate of urea	2357 *b*	3077 *bc*	2473 *b*	
High rate of urea	2252 *b*	2463 *d*	2240 *b*	
X X X X				
Control	2166 *b*	3372 *abc*	1952 *c*	
Low rate of hog manure	2997 *a*	2918 *cd*	3292 *a*	
High rate of hog manure	2855 *a*	3052 *bc*	3602 *a*	
Low rate of urea	2357 *b*	3077 *bc*	2473 *b*	
High rate of urea	2252 *b*	2463 *d*	2440 *b*	

Treatment legend: X X X X indicate year of application
Means followed by the same letter are not significantly different at *P 0.05*.

Table 4. Grain yields at the Riverhurst-dryland site during each year of the project.

Treatment	1999 Canola	2000 Barley	2001 Smf.	2002 Oats
X 0 0 0	kg/ha	kg/ha	kg/ha	Total kg/ha
Control	270 *d*	952 *f*		3130 *ab*
Low rate of hog manure	2252 *a*	2004 *a*		3727 *ab*
High rate of hog manure	2149 *a*	1977 *ab*		4110 *a*
Low rate of urea	1055 *c*	1457 *cde*		2740 *b*
High rate of urea	1613 *b*	1354 *e*		3163 *ab*
X 0 0 X				
Control	270 *d*	952 *f*		2473 *b*
Low rate of hog manure	2252 *a*	2004 *a*		4303 *a*
High rate of hog manure	2149 *a*	1977 *ab*		5430 *a*
Low rate of urea	1055 *c*	1457 *cde*		2243 *b*
High rate of urea	1613 *b*	1354 *e*		2177 *b*
X 0 X 0				
Control	270 *d*	952 *f*		2513 *b*
Low rate of hog manure	2252 *a*	2004 *a*		3660 *ab*
High rate of hog manure	2149 *a*	1977 *ab*		4157 *a*
Low rate of urea	1055 *c*	1457 *cde*		2783 *b*
High rate of urea	1613 *b*	1354 *e*		2870 *b*
X X 0 0				
Control	270 *d*	1003 *f*		4457 *b*
Low rate of hog manure	2252 *a*	1733 *abc*		6053 *a*
High rate of hog manure	2149 *a*	1528 *cde*		5540 *ab*
Low rate of urea	1055 *c*	1707 *bcd*		3190 *c*
High rate of urea	1613 *b*	1422 *ed*		4740 *b*
X X X 0				
Control	270 *d*	1003 *f*		3793 *b*
Low rate of hog manure	2252 *a*	1733 *abc*		5533 *a*
High rate of hog manure	2149 *a*	1528 *cde*		6770 *a*
Low rate of urea	1055 *c*	1707 *bcd*		3333 *b*
High rate of urea	1613 *b*	1422 *ed*		3750 *b*
X X X X				
Control	270 *d*	1003 *f*		4213 *b*
Low rate of hog manure	2252 *a*	1733 *abc*		7350 *a*
High rate of hog manure	2149 *a*	1528 *cde*		6645 *a*
Low rate of urea	1055 *c*	1707 *bcd*		4755 *b*
High rate of urea	1613 *b*	1422 *ed*		4385 *b*

Treatment legend: X X X X indicate year of application

Means followed by the same letter are not significantly different at *P 0.05*.

Table 5. Fall 2002 Plant available Nitrogen (NO_3-N + NH_4-N) levels at Plenty

Treatment	0-30	30-60	0-60	60-90	90-120
[X 0 0 0]					
Control	41 *c*	28 *b*	77 *b*	25 *d*	33 *b*
Low rate of hog manure	76 *b*	22 *b*	99 *b*	25 *d*	39 *ab*
High rate of hog manure	189 *a*	102 *a*	295 *a*	41 *bc*	54 *a*
Low rate of urea	56 *bc*	21 *b*	77 *b*	28 *d*	42 *ab*
High rate of urea	66 *bc*	20 *b*	87 *b*	34 *b*	47 *ab*
[X 0 0 X]					
Control	60 *b*	34 *b*	95 *b*	38 *bc*	55 *c*
Low rate of hog manure	60 *b*	33 *b*	96 *b*	41 *b*	75 *bc*
High rate of hog manure	357 *a*	116 *a*	476 *a*	73 *a*	120 *a*
Low rate of urea	69 *b*	35 *b*	106 *b*	73 *a*	86 *ab*
High rate of urea	85 *b*	28 *b*	116 *b*	45 *bc*	90 *ab*
[X 0 X 0]					
Control	57 *d*	22 *b*	80 *c*	30 *b*	47 *ab*
Low rate of hog manure	149 *ab*	29 *b*	182 *b*	24 *b*	41 *ab*
High rate of hog manure	235 *a*	122 *a*	364 *a*	117 *a*	56 *a*
Low rate of urea	70 *cd*	18 *b*	92 *c*	28 *b*	40 *ab*
High rate of urea	115 *bc*	22 *b*	140 *bc*	29 *b*	57 *c*
[X X 0 0]					
Control	53 *c*	24 *cd*	77 *c*	30 *b*	46 *b*
Low rate of hog manure	161 *b*	50 *b*	217 *b*	37 *b*	76 *a*
High rate of hog manure	326 *a*	201 *a*	533 *a*	77 *a*	65 *ab*
Low rate of urea	43 *c*	16 *d*	59 *c*	28 *b*	49 *b*
High rate of urea	58 *c*	33 *bc*	91 *c*	36 *b*	63 *ab*
[X X X 0]					
Control	70 *c*	32 *c*	103 *c*	41 *b*	79 *ab*
Low rate of hog manure	310 *b*	70 *b*	380 *b*	47 *b*	96 *a*
High rate of hog manure	867 *a*	329 *a*	1209 *a*	138 *a*	85 *a*
Low rate of urea	77 *c*	26 *c*	110 *c*	20 *c*	52 *b*
High rate of urea	115 *c*	32 *c*	149 *c*	49 *b*	79 *ab*
[X X X X]					
Control	71 *d*	31 *c*	103 *d*	42 *b*	63 *ab*
Low rate of hog manure	332 *b*	103 *b*	457 *b*	54 *ab*	77 *ab*
High rate of hog manure	620 *a*	249 *a*	870 *a*	85 *a*	72 *ab*
Low rate of urea	179 *c*	25 *c*	206 *c*	37 *b*	55 *a*
High rate of urea	171 *c*	35 *c*	214 *c*	41 *b*	79 *ab*

Treatment legend: [X X X X] indicate year of application

Means followed by the same letter are not significantly different at *P 0.05*.

Table 6. Fall 2002 Plant available Nitrogen (NO_3-N + NH_4-N) levels at Beechy

Treatment	0-30	30-60	0-60	60-90	90-120
[X 0 0 0]					
Control	17	17 *ab*	34 *b*	25 *b*	31 *b*
Low rate of hog manure	19	13 *b*	34 *b*	26 *b*	35 *ab*
High rate of hog manure	16	36 *a*	54 *b*	59 *a*	50 *a*
Low rate of urea	19	14 *b*	34 *b*	22 *b*	24 *b*
High rate of urea	12	16 *ab*	30 *b*	19 *b*	26 *b*
[X 0 0 X]					
Control	13 *b*	19 *b*	33 *b*	41 *b*	41 *bc*
Low rate of hog manure	13 *b*	17 *b*	32 *b*	46 *b*	56 *ab*
High rate of hog manure	38 *a*	137 *a*	176 *a*	111 *a*	67 *a*
Low rate of urea	18 *b*	16 *b*	34 *b*	24 *c*	34 *c*
High rate of urea	14 *b*	13 *b*	29 *b*	23 *c*	29 *c*
[X 0 X 0]					
Control	12 *c*	6 *d*	23 *c*	29 *bc*	33 *b*
Low rate of hog manure	40 *b*	59 *b*	101 *b*	40 *b*	49 *ab*
High rate of hog manure	169 *a*	195 *a*	383 *a*	81 *a*	68 *a*
Low rate of urea	15 *c*	12 *cd*	27 *c*	26 *c*	39 *b*
High rate of urea	40 *b*	20 *c*	61*b*	31 *bc*	40 *b*
[X X 0 0]					
Control	15 *b*	25 *c*	42 *c*	28 *c*	28 *bc*
Low rate of hog manure	54 *a*	104 *b*	160 *b*	62 *b*	37 *b*
High rate of hog manure	91 *a*	286 *a*	380 *a*	175 *a*	72 *a*
Low rate of urea	15 *b*	19 *c*	34 *c*	31 *c*	40 *b*
High rate of urea	12 *b*	18 *c*	30 *c*	32 *c*	24 *c*
[X X X 0]					
Control	11 *d*	17 *c*	27 *d*	28 *c*	32 *d*
Low rate of hog manure	8 *b*	109 *b*	206 *b*	121 *b*	93 *b*
High rate of hog manure	323 *a*	311 *a*	643 *a*	241 *a*	158 *a*
Low rate of urea	38 *c*	23 *c*	61 *c*	33 *c*	60 *bc*
High rate of urea	54 *bc*	15 *c*	69 *c*	33 *c*	56 *c*
[X X X 0]					
No manure applied at Beechy in 2001/2002					

Treatment legend: [X X X X] indicate year of application
Means followed by the same letter are not significantly different at *P 0.05*.

Table 7. Fall 2002 Plant available Nitrogen (NO_3-N + NH_4-N) levels at Riverhurst-irrigated

Treatment	0-30	30-60	0-60	60-90	90-120
X 0 0 0					
Control	56	19 *b*	76 *b*	13 *bc*	17
Low rate of hog manure	48	14 *b*	62 *b*	8 *c*	14
High rate of hog manure	63	72 *a*	153 *a*	56 *a*	22
Low rate of urea	60	20 *b*	80 *b*	21 *b*	25
High rate of urea	54	24 *b*	77 *b*	22 *b*	14
X 0 0 X					
Control	60 *b*	21 *b*	82 *b*	21 *b*	30
Low rate of hog manure	80 *b*	36 *b*	116 *b*	30 *ab*	24
High rate of hog manure	128 *a*	81 *a*	225 *a*	55 *a*	33
Low rate of urea	63 *b*	26 *b*	91 *b*	25 *ab*	32
High rate of urea	70 *b*	45 *ab*	118 *b*	17 *b*	18
X 0 X 0					
Control	52 *b*	24 *b*	77 *b*	26 *b*	51 *a*
Low rate of hog manure	54 *b*	27 *ab*	83 *b*	18 *b*	16 *b*
High rate of hog manure	77 *a*	53 *a*	136 *a*	93 *a*	24 *ab*
Low rate of urea	50 *b*	21 *b*	71 *b*	22 *b*	29 *ab*
High rate of urea	44 *b*	19 *b*	64 *b*	18 *b*	26 *ab*
X X 0 0					
Control	40 *c*	17 *b*	58 *b*	18 *b*	59 *a*
Low rate of hog manure	56 *ab*	24 *b*	81 *b*	24 *b*	19 *b*
High rate of hog manure	78 *a*	51 *a*	142 *a*	69 *a*	63 *a*
Low rate of urea	51 *bc*	20 *b*	71 *b*	20 *b*	22 *b*
High rate of urea	46 *bc*	16 *b*	63 *b*	26 *b*	28 *ab*
X X X 0					
Control	51 *bc*	21 *b*	75 *b*	14 *c*	15 *b*
Low rate of hog manure	68 *ab*	33 *ab*	102 *ab*	61 *ab*	45 *a*
High rate of hog manure	75 *a*	60 *a*	146 *a*	131 *a*	30 *ab*
Low rate of urea	48 *c*	27 *b*	76 *b*	27 *bc*	30 *ab*
High rate of urea	67 *ab*	41 *ab*	112 *ab*	62 *b*	34 *ab*
X X X X					
Control	47 *b*	16 *c*	64 *d*	19 *b*	15
Low rate of hog manure	64 *b*	55 *b*	132 *b*	55 *a*	28
High rate of hog manure	113 *a*	243 *a*	359 *a*	85 *a*	23
Low rate of urea	54 *a*	58 *bc*	83 *cd*	22 *b*	18
High rate of urea	65 *b*	37 *b*	104 *bc*	44 *ab*	23

Treatment legend: X X X X indicate year of application

Means followed by the same letter are not significantly different at *P 0.05.*

Table 8. Fall 2002 Plant available Nitrogen (NO_3-N + NH_4-N) levels at Riverhurst-dryland

Treatment	0-30	30-60	0-60	60-90	90-120
[X 0 0 0]					
Control	13 *b*	11 *b*	24 *b*	9 *b*	13 *a*
Low rate of hog manure	14 *b*	11 *b*	25 *b*	12 *b*	6 *c*
High rate of hog manure	33 *a*	45 *a*	88 *a*	28 *a*	22 *a*
Low rate of urea	14 *ab*	7 *b*	22 *b*	12 *b*	12 *b*
High rate of urea	13 *b*	11 *b*	23 *b*	13 *b*	15 *a*
[X 0 0 X]					
Control	10 *c*	7 *c*	17 *c*	11 *bc*	7 *b*
Low rate of hog manure	58 *ab*	28 *b*	91 *b*	15 *ab*	11 *ab*
High rate of hog manure	103 *a*	121 *a*	234 *a*	22 *a*	15 *a*
Low rate of urea	37 *b*	19 *b*	58 *b*	9 *c*	11 *ab*
High rate of urea	34 *b*	21 *b*	55 *b*	13 *bc*	14 *a*
[X 0 X 0]					
Control	15 *b*	8 *d*	24 *c*	11 *c*	10 *c*
Low rate of hog manure	32 *ab*	29 *c*	63 *b*	15 *bc*	20 *ab*
High rate of hog manure	58 *a*	155 *a*	219 *a*	25 *a*	28 *a*
Low rate of urea	15 *b*	10 *d*	25 *c*	11 *c*	12 *bc*
High rate of urea	39 *a*	65 *b*	105 *b*	20 *ab*	24 *a*
[X X 0 0]					
Control	9 *c*	8 *c*	17 *c*	13 *c*	22 *a*
Low rate of hog manure	58 *a*	47 *ab*	107 *a*	23 *ab*	17 *a*
High rate of hog manure	32 *ab*	98 *a*	137 *a*	35 *a*	28 *a*
Low rate of urea	19 *bc*	12 *c*	32 *bc*	17 *bc*	29 *a*
High rate of urea	19 *bc*	25 *b*	45 *b*	26 *ab*	25 *a*
[X X X 0]					
Control	15 *c*	18 *c*	35 *c*	7 *c*	15 *b*
Low rate of hog manure	95 *a*	117 *a*	231 *a*	27 *b*	21 *ab*
High rate of hog manure	92 *a*	244 *a*	404 *a*	48 *a*	18 *ab*
Low rate of urea	23 *bc*	24 *bc*	54 *bc*	17 *b*	28 *a*
High rate of urea	41 *ab*	43 *b*	87 *b*	21 *b*	24 *ab*
[X X X X]					
Control	23 *d*	17 *d*	40 *d*	14 *c*	30 *a*
Low rate of hog manure	171 *a*	134 *b*	332 *ab*	27 *b*	16 *b*
High rate of hog manure	112 *ab*	319 *a*	451 *a*	125 *a*	20 *ab*
Low rate of urea	43 *cd*	56 *c*	101 *c*	18 *bc*	18 *ab*
High rate of urea	58 *bc*	118 *bc*	179 *bc*	28 *b*	12 *b*

Treatment legend: [X X X X] indicate year of application

Means followed by the same letter are not significantly different at *P 0.05*.

Table 9. Soil physical properties in the field plots after 4 years of annual applications of hog manure or urea. Beechy and Riverhurst-dryland data were obtained after 3 years of annual applications of hog manure or urea fertilizer. (HM = high rate of annual manure application, Urea = high rate of annual urea application).

Soil bulk density (Mg/m^3)

	Beechy			Plenty*		
Depth	HM	Urea	Control	HM	Urea	Control
0-5 cm	1.012	1.042	1.048	1.060	1.070	1.120
5-10 cm	1.302	1.354	1.389			
10-15 cm	1.369	1.398	1.431			
	Riverhurst-irrigated			Riverhurst-dryland*		
Depth	HM	Urea	Control	HM	Urea	Control
0-5 cm	1.182	1.144	1.318	1.240	1.270	1.260
5-10 cm	1.302	1.354	1.389			
10-15 cm	1.369	1.398	1.431			

- values represent the 0-15 cm depth

Soil Strength; penetrometer resistance (kPa)

	Beechy			Plenty		
Depth	HM	Urea	Control	HM	Urea	Control
0-5 cm	6	6	8	12 *a*	9 *ab*	7 *b*
5-10 cm	288	302	487	235	335	365
10-15 cm	537	559	564	409	454	442
	Riverhurst-irrigated			Riverhurst-dryland		
Depth	HM	Urea	Control	HM	Urea	Control
0-5 cm	67	54	42	10	7	12
5-10 cm	343	287	356	134	152	162
10-15 cm	376	420	407	275	331	324

Means followed by the same letter are not significantly different at *P 0.05.*

Soil Strength; shear vane resistance (kPa)

	Beechy			Plenty		
Depth	HM	Urea	Control	HM	Urea	Control
0-5 cm	0	0	0	2	3	4
5-10 cm	308	366	413	25	52	65
10-15 cm	452	490	506	78	88	74
	Riverhurst-irrigated			Riverhurst-dryland		
Depth	HM	Urea	Control	HM	Urea	Control
0-5 cm	42	33	56	4	3	4
5-10 cm	421	369	372	13	9	9
10-15 cm	394	493	433	20	24	23

Table 10. Cumulative water infiltration (I_{20}), saturated hydraulic conductivity (K-sat) and aggregate size distribution in the field plots after 4 years of annual applications of hog manure or urea. Beechy and Riverhurst-dryland data were obtained after 3 years of annual applications of hog manure or urea fertilizer. (HM = high rate of annual manure application, Urea = high rate of annual urea application

Cumulative water infiltration (I_{20}) in cm (depth of water infiltrated after 20 minutes).

	HM	Urea	Control
Beechy	7.5	7.8	6.1
Plenty	15.0	15.0	14.0
Riverhurst-irrigated	6.3	5.7	4.2
Riverhurst-dryland	7.8	9.4	8.5

Saturated hydraulic conductivity (K-sat) in 10^{-5} m/s

	HM	Urea	Control
Beechy	9.52	6.99	9.44
Plenty	3.19	3.14	3.01
Riverhurst-irrigated	4.85	6.22	3.06
Riverhurst-dryland	1.47	1.89	1.28

Mean-weight diameter of soil aggregates (mm)

	HM	Urea	Control
Beechy	14.7	14.0	12.3
Plenty	8.3 *a*	15.7 *b*	12.8 *b*
Riverhurst-irrigated	1.6	7.0	8.5
Riverhurst-dryland	10.2	13.7	11.6

Means followed by the same letter are not significantly different at *P 0.05*.

Table 11. Soil salinity (EC), soil reaction (pH), and soil sodicity (SAR) in the top 15 cm the field plots after 1 and 3 years of high rates of annual applications of hog manure or urea. (HM = high rate of annual manure application).

Soil reaction (pH).

	After the 1st year		After the 3rd year	
	HM	Control	HM	Control
Beechy	7.86	8.44	ND	ND
Plenty	8.27	8.30	7.40 *a*	7.70 *b*
Riverhurst-irrigated	7.64	8.09	ND	ND
Riverhurst-dryland	8.08	8.10	7.70	6.70

Soil salinity (EC 1:1) in dS/m

	After the 1st year		After the 3rd year	
	HM	Control	HM	Control
Beechy	0.95 *a*	0.48 *b*	1.97 *a*	0.48 *b*
Plenty	0.74	0.61	2.50 *a*	0.60 *b*
Riverhurst-irrigated	1.82 *a*	0.79 *b*	2.08 *a*	0.79 *b*
Riverhurst-dryland	0.44	0.32	1.40	1.10

Soil sodicity (SAR)

	After the 1st year		After the 3rd year	
	HM	Control	HM	Control
Beechy	0.91	1.23	1.73	1.23
Plenty	ND	ND	1.35 *a*	1.21 *b*
Riverhurst-irrigated	1.14	1.26	1.21	1.26
Riverhurst-dryland	ND	ND	0.80	0.78

Means followed by the same letter are not significantly different at *P 0.05*.
ND = no data available

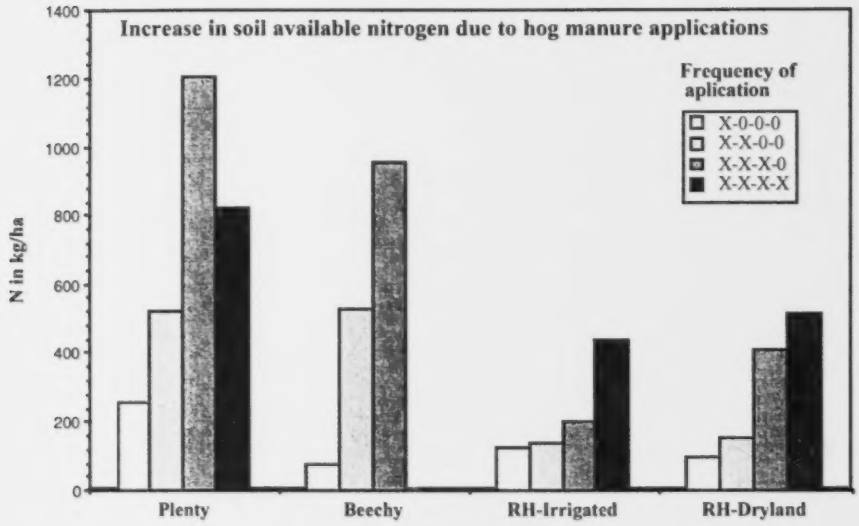


Fig. 1. Soil N levels (NH_4-N plus NO_3-N) in the fall of 2002 in the 0-120 cm depth

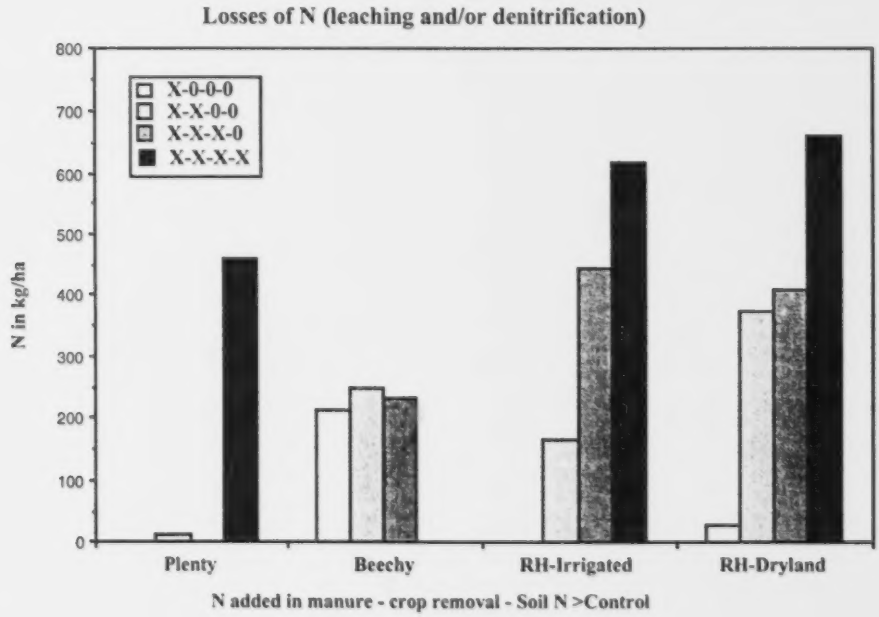


Fig. 2. Unaccounted for N (N-losses) as a function of frequency of hog manure application

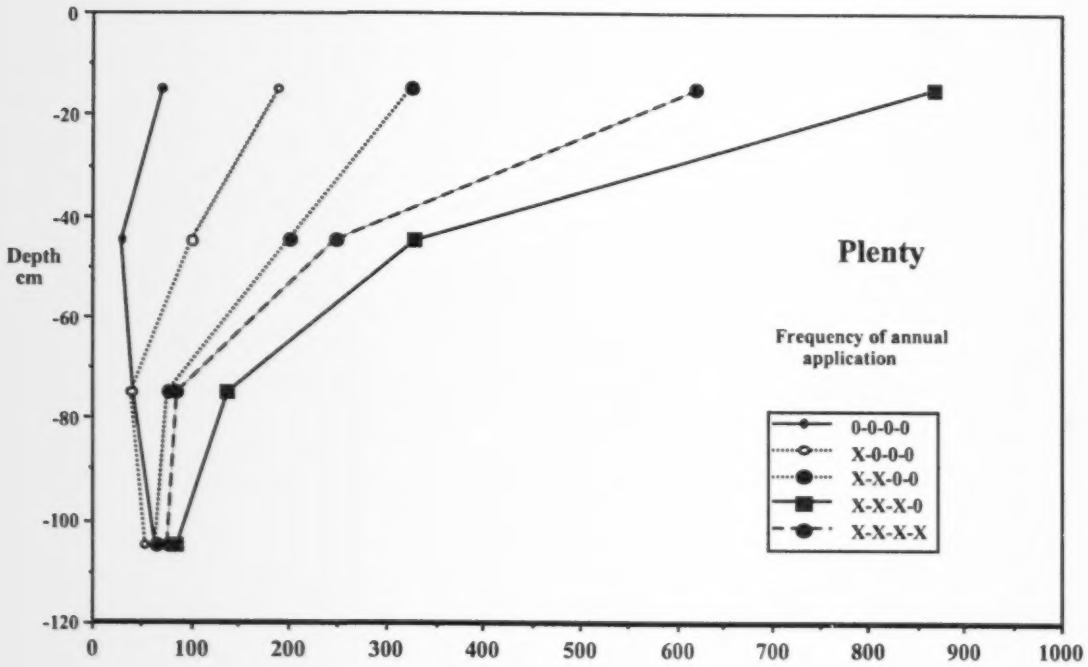


Fig. 3 Soil N levels (kg/ha of NH4-N + NO3-N) in the plots treated with high rates of manure.

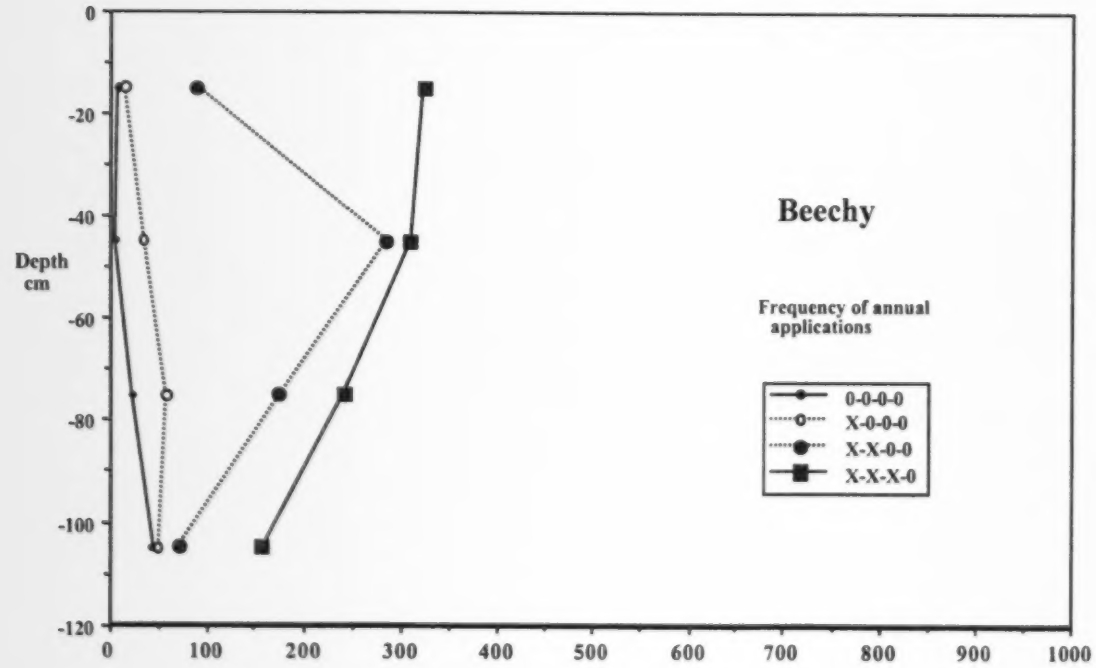


Fig. 4. Soil N levels (kg/ha of NH4-N + NO3-N) in the plots treated with high rates of manure.

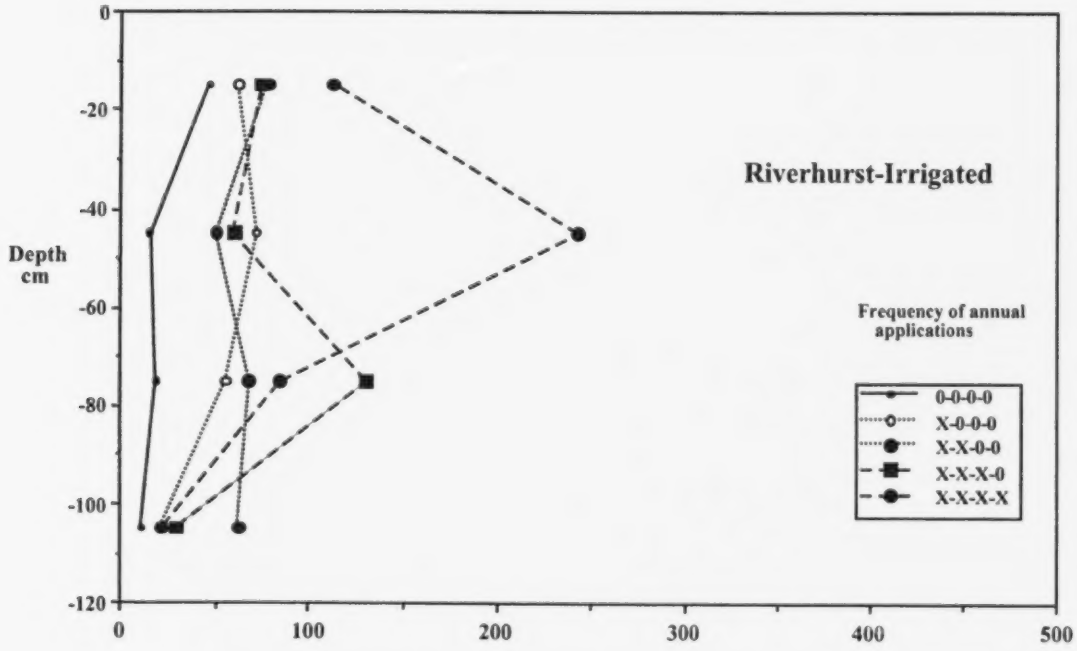


Fig. 5. Soil N levels (kg/ha of NH4-N + NO3-N) in the plots treated with high rates of manure

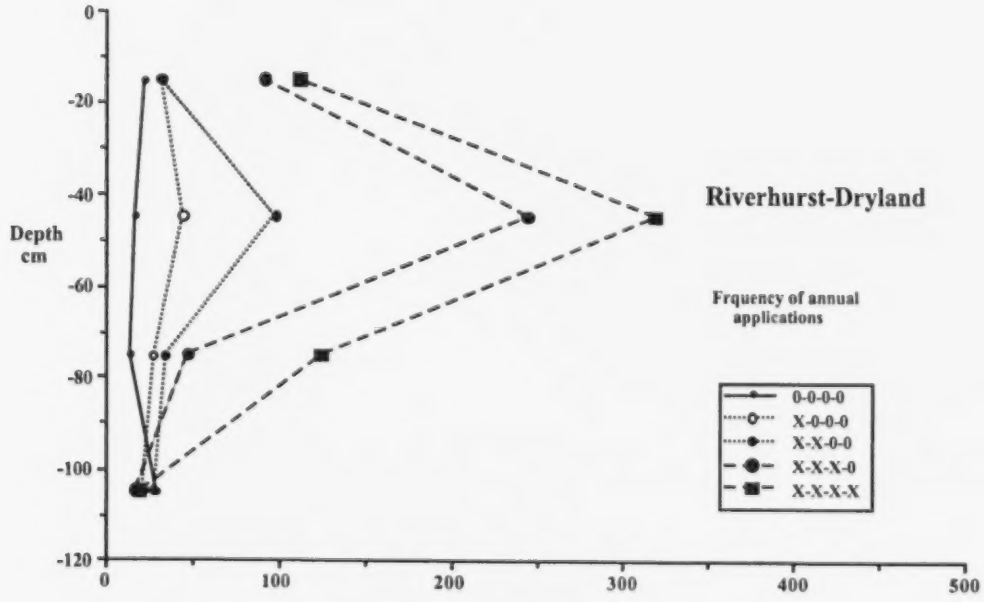


Fig. 6. Soil N levels (kg/ha of NH4-N + NO3-N) in the plots treated with high rates of manure.

Appendix I. Analysis of Hog Manure

Nutrient analysis of the hog manure in ppm

	Beechy	Plenty	RH-irrigated	RH-dryland
	---------- ppm ----------			
Total N	3769	3111	3358	3406
Total P	335	164	289	333
Available				
NH_4-N	2984	2520	2480	2564
P	75	98	98	97
K	1493	1400	1357	1367
Ca	423	243	388	411
Mg	188	54	156	192
Na	347	982	425	436
Fe	33	13.4	27	31
Mn	5.5	1.8	4.7	5.7
Cu	3.3	1.3	2.8	2.9
Zn	17	9.4	13.5	14.3
B	1.1	0.8	<0.1	<0.1

Quantity of nutrients applied in kg/ha from 4 annual applications at the high rate

	Beechy	Plenty	RH-irrigated	RH-dryland
	---------- kg/ha ----------			
Total N	2112	1382	1825	1851
Total P	188	73	157	181
Available				
NH4-N	1672	1120	1348	1393
P	42	44	53	53
K	837	622	737	743
Ca	237	108	211	223
Mg	105	24	85	104
Na	194	436	231	237
Fe	18.5	6.0	14.7	16.8
Mn	3.1	0.8	2.6	3.1
Cu	1.8	0.6	1.5	1.6
Zn	9.5	4.2	7.3	7.8
B	0.6	0.4	<0.1	<0.1

Appendix II. Details of crop yields during the 2002 growing season

Table 1. 2002 Chick pea yields at the Beechy site.

Treatment	Grain	Straw	Total	Grain/Straw
X 0 0 0	kg/ha	kg/ha	kg/ha	ratio
Control	1763 *b*	2444 *b*	4207 *b*	0.72
Low rate of hog manure	2523 *a*	3134 *b*	5657 *ab*	0.81
High rate of hog manure	2191 *ab*	4036 *a*	6227 *a*	0.54
Low rate of urea	1943 *ab*	3143 *b*	5087 *ab*	0.62
High rate of urea	2017 *ab*	3070 *b*	5087 *ab*	0.66
X 0 0 X				
Control	2126 *ab*	3264 *b*	5390 *b*	0.65
Low rate of hog manure	1834 *ab*	3193 *b*	5027 *b*	0.57
High rate of hog manure	2714 *a*	4663 *a*	7377 *a*	0.58
Low rate of urea	2139 *ab*	2894 *b*	5033 *b*	0.74
High rate of urea	1756 *b*	2694 *b*	4450 *b*	0.65
X 0 X 0				
Control	2113 *ab*	3107 *bc*	5220 *b*	0.68
Low rate of hog manure	2009 *ab*	3944 *ab*	5953 *a*	0.51
High rate of hog manure	1828 *ab*	4035 *a*	5863 *ab*	0.45
Low rate of urea	2302 *ab*	3509 *abc*	5810 *ab*	0.66
High rate of urea	2118 *ab*	3062 *c*	5180 *b*	0.69
X X 0 0				
Control	2100 *ab*	2790 *b*	4890 *b*	0.75
Low rate of hog manure	2653 *a*	3627 *b*	6280 *ab*	0.73
High rate of hog manure	2329 *ab*	4918 *a*	7247 *a*	0.47
Low rate of urea	2355 *ab*	3165 *b*	5520 *b*	0.74
High rate of urea	1915 *ab*	2782 *b*	4697 *b*	0.69
X X X 0				
Control	2466 *a*	3150 *bc*	5617 *b*	0.78
Low rate of hog manure	2057 *ab*	3950 *ab*	6007 *a*	0.52
High rate of hog manure	1519 *b*	4528 *a*	6047 *a*	0.34
Low rate of urea	2100 *ab*	3310 *bc*	5410 *b*	0.63
High rate of urea	1728 *ab*	2992 *c*	4720 *b*	0.58
X X X X				
Control	2173 *ab*	3034 *b*	5207 *b*	0.72
Low rate of hog manure	1632 *b*	4372 *a*	6003 *ab*	0.37
High rate of hog manure	2044 *ab*	4913 *a*	6003 *ab*	0.42
Low rate of urea	2300 *ab*	3367 *b*	5667 *ab*	0.81
High rate of urea	1964 *ab*	2853 *b*	4817 *b*	0.69

Treatment legend: X X X X indicate year of application

Means followed by the same letter are not significantly different at *P 0.05*.

Table 2. 2002 Total dry matter (Oats biomass) yields at Riverhurst-dryland .

Treatment	Total
X 0 0 0	kg/ha
Control	3130 *ab*
Low rate of hog manure	3727 *ab*
High rate of hog manure	4110 *a*
Low rate of urea	2740 *b*
High rate of urea	3163 *ab*
X 0 0 X	
Control	2473 *b*
Low rate of hog manure	4303 *a*
High rate of hog manure	5430 *a*
Low rate of urea	2243 *b*
High rate of urea	2177 *b*
X 0 X 0	
Control	2513 *b*
Low rate of hog manure	3660 *ab*
High rate of hog manure	4157 *a*
Low rate of urea	2783 *b*
High rate of urea	2870 *b*
X X 0 0	
Control	4457 *b*
Low rate of hog manure	6053 *a*
High rate of hog manure	5540 *ab*
Low rate of urea	3190 *c*
High rate of urea	4740 *b*
X X X 0	
Control	3793 *b*
Low rate of hog manure	5533 *a*
High rate of hog manure	6770 *a*
Low rate of urea	3333 *b*
High rate of urea	3750 *b*
X X X X	
Control	4213 *b*
Low rate of hog manure	7350 *a*
High rate of hog manure	6645 *a*
Low rate of urea	4755 *b*
High rate of urea	4385 *b*

Treatment legend: X X X X indicate year of application

Means followed by the same letter are not significantly different at *P 0.05*.

Appendix III. Details of crop yields during the 2001 growing season

Table 1. 2001 Growing season, wheat yields at the Plenty site.

Treatment			Grain	Straw	Total	Grain/Straw
'99	'00	'01	kg/ha	kg/ha	kg/ha	ratio
0	0	0	798 *cd*	1075 *ef*	1873 *d*	0.74
h	0	0	828 *bcd*	1213 *def*	2041 *d*	0.68
h	0	h	808 *cd*	1483 *bcde*	2292 *abcd*	0.54
h	h	0	810 *cdef*	1250 *cdef*	2060 *cd*	0.65
h	h	h	840 *bcd*	1344 *bcdef*	2184 *bcd*	0.63
H	0	0	1114 *a*	1525 *abcd*	2639 *abc*	0.73
H	0	H	952 *abc*	1903 *a*	2855 *a*	0.50
H	H	0	1038 *ab*	1658 *abc*	2697 *ab*	0.63
H	H	H	1081 *a*	1711 *ab*	2792 *a*	0.63
u	u	u	718 *a*	1043 *f*	1762 *d*	0.69
U	U	U	699 *d*	1182 *def*	1881 *d*	0.59

Treatment legend: "99, '00, and '01 indicates year of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Table 2. 2001 Growing season, Durum wheat yields at the Beechy site.

Treatment			Grain	Straw	Total	Grain/Straw
'99	'00	'01	kg/ha	kg/ha	kg/ha	ratio
0	0	0	528	1147	1675	0.46
h	0	0	543	1453	1995	0.37
h	0	h	413	1480	1893	0.28
h	h	0	495	1425	1920	0.35
h	h	h	405	1312	1717	0.31
H	0	0	464	1601	2065	0.29
H	0	H	387	1575	1962	0.25
H	H	0	467	1627	2093	0.29
H	H	H	429	1563	1993	0.27
u	u	u	464	1089	1553	0.43
U	U	U	406	994	1400	0.41

Treatment legend: "99, '00, and '01 indicates year of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Table 3. 2001 Growing season, Barley yields at the Riverhurst-Irrigated site.

Treatment			Grain	Straw	Total	Grain/Straw
'99	'00	'01	kg/ha	kg/ha	kg/ha	ratio
0	0	0	1903 *c*	2195 *e*	4098 *e*	0.87
h	0	0	3170 *a*	3342 *d*	6512 *c*	0.95
h	0	h	3177 *a*	4570 *bc*	7747 *b*	0.70
h	h	0	3167 *ab*	4933 *ab*	8100 *ab*	0.64
h	h	h	3292 *a*	4925 *ab*	8217 *ab*	0.67
H	0	0	3522 *a*	4215 *c*	7737 *b*	0.84
H	0	H	3507 *a*	5187 *a*	8693 *a*	0.68
H	H	0	3637 *a*	5277 *a*	8913 *a*	0.69
H	H	H	3602 *a*	5308 *a*	8910 *a*	0.68
u	u	u	2473 *b*	3208 *d*	5682 *cd*	0.77
U	U	U	2440 *b*	3155 *d*	5595 *d*	0.77

Treatment legend: "99, '00, and '01 indicates year of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Table 4. 2001 Growing season, plant Nitrogen content and percentage protein of Wheat yields at the Plenty site.

Treatment			Grain	Straw	Total	Grain protein
'99	'00	'01	kg/ha	kg/ha	kg/ha	%
0	0	0	21.2 *c*	28.6 *e*	49.8 *e*	15.2 *e*
h	0	0	24.2 *c*	35.6 *cde*	59.8 *cde*	17.0 *d*
h	0	h	26.6 *bc*	49.0 *bc*	75.6 *bcd*	18.6 *abc*
h	h	0	27.0 *bc*	41.7 *bcde*	68.7 *cde*	19.1 *abc*
h	h	h	27.4 *bc*	44.2 *bcd*	71.6 *bcde*	18.7 *abc*
H	0	0	35.3 *a*	48.5 *bc*	83.7 *abc*	18.3 *bcd*
H	0	H	33.0 *ab*	66.1 *a*	99.1 *a*	20.0 *a*
H	H	0	35.5 *ab*	56.9 *ab*	92.4 *ab*	19.7 *ab*
H	H	H	35.1 *a*	55.7 *ab*	90.8 *ab*	18.7 *abc*
u	u	u	21.9 *c*	31.8 *de*	53.7 *de*	17.5 *cd*
U	U	U	22.6 *c*	38.3 *cde*	60.9 *de*	18.6 *abc*

Treatment legend: "99, '00, and '01 indicates year (fall) of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Table 5. 2001 Growing season, plant Nitrogen content and percentage protein of Durum yields at the Beechy site.

Treatment			Grain	Straw	Total	Grain protein
'99	'00	'01	kg/ha	kg/ha	kg/ha	%
0	0	0	17.3	37.7	55.0	18.9
h	0	0	17.5	47.7	65.2	18.8
h	0	h	13.9	49.9	63.8	19.3
h	h	0	16.0	46.4	62.4	18.8
h	h	h	13.4	43.5	56.9	19.2
H	0	0	14.9	51.1	66.0	18.3
H	0	H	13.2	53.9	67.1	19.3
H	H	0	15.2	53.4	68.5	18.5
H	H	H	14.3	52.4	66.8	19.2
u	u	u	14.9	34.9	49.8	18.4
U	U	U	13.1	32.2	45.4	18.7

Treatment legend: "99, '00, and '01 indicates year of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Table 6. 2001 Growing season, plant Nitrogen content and percentage protein of Barley yields at the Riverhurst-Irrigated site.

Treatment			Grain	Straw	Total	Grain protein
'99	'00	'01	kg/ha	kg/ha	kg/ha	%
0	0	0	31.3 *e*	36.2 *d*	67.4 *f*	10.3 *c*
h	0	0	57.6 *d*	60.7 *c*	118.3 *e*	11.3 *bc*
h	0	h	72.6 *c*	104.3 *b*	176.9 *d*	14.3 *a*
h	h	0	77.7 *bc*	120.8 *a*	198.5 *bc*	15.3 *a*
h	h	h	79.1 *abc*	118.3 *a*	197.4 *bc*	15.0 *a*
H	0	0	84.4 *ab*	102.6 *b*	187.0 *cd*	15.1 *a*
H	0	H	85.9 *ab*	127.1 *ab*	213.0 *ab*	15.3 *a*
H	H	0	87.2 *ab*	126.9 *a*	214.1 *ab*	15.0 *a*
H	H	H	89.3 *a*	131.6 *a*	221.0 *a*	15.5 *a*
u	u	u	48.1 *d*	62.6 *c*	110.7 *e*	12.1 *b*
U	U	U	56.0 *d*	72.3 *c*	128.3 *e*	14.3 *a*

Treatment legend: "99, '00, and '01 indicates year of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Appendix IV. Details of crop yields during the 2000 growing season

Table 1. Crop growth characteristics at the Beechy - Lentils site

Treatment '99	Treatment '00	Grain yield	Straw yields	Total yield	Protein
		kg/ha			-- % --
0	0	2015_{abcd}	2598_{def}	4612_{def}	25.1_{c}
u	0	2372_{a}	3256_{d}	5628_{cd}	25.0_{c}
u	u	2089_{def}	2664_{def}	4753_{def}	24.9_{c}
U	0	1829_{d}	2152_{f}	3981_{f}	25.3_{c}
U	U	1932_{abcd}	2282_{ef}	4214_{ef}	24.8_{c}
h	0	2222_{ab}	3951_{c}	6173_{bc}	25.5_{c}
h	h	2218_{abc}	5141_{a}	7359_{a}	27.2_{b}
H	0	1851_{bcd}	4913_{ab}	6764_{ab}	27.5_{b}
H	H	1869_{bcd}	4402_{bc}	6271_{bc}	29.0_{a}

Treatment legend: "99, '00, and '01 indicates year of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Table 2. Crop growth characteristics at the Plenty – Canary Seed site

Treatment '99	Treatment '00	Grain yield	Straw yields	Total yield	Protein
		kg/ha			-- % --
0	0	615_{bc}	1557_{bc}	2172_{cd}	16.2_{d}
u	0	601_{bc}	1354_{c}	1956_{cd}	16.1_{d}
u	u	634_{bc}	2402_{a}	3037_{a}	18.3_{c}
U	0	582_{bc}	1247_{c}	1879_{d}	16.2_{d}
U	U	702_{b}	1768_{bc}	2470_{abc}	20.1_{b}
h	0	873_{a}	2131_{ab}	3004_{ab}	20.7_{b}
h	h	591_{bc}	1789_{bc}	2380_{bcd}	22.7_{a}
H	0	920_{a}	2138_{ab}	3058_{a}	21.8_{ab}
H	H	587_{bc}	1567_{bc}	2153_{cd}	22.5_{a}

Treatment legend: "99, '00, and '01 indicates year of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Table 3. Crop growth characteristics at the Riverhurst – Irrigated Barley site

Treatment '99	Treatment '00	Grain yield	Straw yields	Total yield	Protein
		---------- kg/ha ----------			-- % --
0	0	3440_{ab}	4564_{b}	8005_{cde}	11.1_{e}
u	u	3669_{a}	4519_{b}	8188_{cde}	11.6_{e}
u	0	3077_{bc}	4714_{b}	7791_{cde}	13.5_{d}
U	0	3431_{ab}c	4862_{b}	8293_{cde}	11.7_{e}
U	U	2463_{d}	4811_{b}	7274_{e}	14.7_{bc}
h	0	3658_{a}	5897_{a}	9554_{ab}	14.1_{cd}
h	h	2918_{cd}	5913_{a}	8831_{abcd}	15.7_{a}
H	0	3591_{ab}	6156_{a}	9747_{a}	15.9_{a}
H	H	3052_{bc}	5871_{a}	8923_{abc}	15.4_{ab}

Treatment legend: "99, '00, and '01 indicates year of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Table 4. Crop growth characteristics at the Riverhurst – Dryland Barley site

Treatment '99	Treatment '00	Grain yield	Straw yields	Total yield	Protein
		---------- kg/ha ----------			-- % --
0	0	978_{f}	1504_{d}	2482_{c}	6.9_{e}
u	0	1457_{cde}	1969_{c}	3426_{cd}	7.7_{de}
u	u	1707_{bcde}	2466_{b}	4172_{ab}	11.9_{c}
U	0	1354_{e}	1823_{cd}	3177_{d}	8.6_{d}
U	U	1422_{cd}	2571_{ab}	3992_{bc}	14.1_{b}
h	0	2004_{a}	2450_{b}	4454_{ab}	10.8_{c}
h	h	1733_{abc}	2739_{ab}	4472_{ab}	15.3_{ab}
H	0	1977_{ab}	2766_{ab}	4743_{a}	14.0_{b}
H	H	1528_{cde}	2869_{a}	4398_{ab}	15.9_{ab}

Treatment legend: "99, '00, and '01 indicates year of application
h = low rate of hog manure, H = high rate of hog manure, u = low rate of urea, U = high rate of urea
Means followed by the same letter are not significantly different at *P 0.05*.

Appendix V. Details of crop yields during the 1999 growing season

Table 1. 1999 Growing season, crop growth characteristics.

Treatment	Grain yield	Straw yields	Total yield	Grain Harvest Index
	---------- kg/ha ----------			-- % --
		Beechy – Durum wheat		
Control	1617 *c*	3105 *c*	4722 *c*	34.5
Urea - low rate	2296 *b*	4639 *b*	6935 *b*	33.4
Urea – high rate	2269 *b*	4815 *b*	7084 *b*	32.3
Hog Manure – low rate	3008 *a*	6477 *a*	9486 *a*	32.0
Hog Manure – high rate	2965 *a*	6152 *a*	9117 *a*	32.5
		Plenty – Spring wheat		
Control	1607 *d*	2257 *c*	3864 *d*	41.7
Urea - low rate	3072 *c*	4357 *b*	7429 *c*	41.4
Urea – high rate	4023 *b*	5848 *a*	9871 *b*	41.0
Hog Manure – low rate	4488 *a*	6358 *a*	10847 *a*	41.5
Hog Manure – high rate	4514 *a*	6313 *a*	10827 *a*	41.9
		Riverhurst-irrigated – Beans		
Control	2169 *b*	2174 *b*	4343 *b*	50.6
Urea - low rate	2357 *b*	2449 *b*	4807 *b*	49.4
Urea – high rate	2252 *b*	2505 *b*	4757 *b*	48.9
Hog Manure – low rate	2997 *a*	3153 *a*	6151 *a*	48.4
Hog Manure – high rate	3449 *a*	2855 *a*	6304 *a*	45.4
		Riverhurst-dryland – Canola		
Control	270 *d*	856 *d*	1125 *d*	21.3
Urea - low rate	1055 *c*	2573 *c*	3628 *c*	28.7
Urea – high rate	1613 *b*	3658 *b*	5270 *b*	29.8
Hog Manure – low rate	2252 *a*	5623 *a*	7874 *a*	28.6
Hog Manure – high rate	2149 *a*	5708 *a*	7857 *a*	27.5

Treatment means followed by a different letter are significantly different ($P_{0.05}$)

Appendix VI. Growth Chamber Study

A growth chamber study was completed to determine the effect of repeated applications on the quality of the soil and on the quality of crops. Two soils were used: Willows Association, clay to clay loam (soil from Beechy site) and a Birsay sandy loam (soil from Riverhurst site). Three rates of hog manure (0, 4,000 and 8,000 gallons per acre) were are applied to soil in 6" containers. The manure applications were repeated four times. Different crops were grown after each application, Canola, Barley, Canola, and Barley. The soils were periodically watered by applying water on the surface or on the saucer at the bottom of the pot. Crop yield, plant nutrient uptake, soil physical and chemical analyses were measured during the experiment. The results are presented in Tables 1, 2, 3, and 3

a) Effect of hog manure application on soil fertility
Both available nitrogen supply rates and available phosphorus supply rates (resin membrane method) were increased by the application of hog manure. The N supply rates continued to increase up until the 3rd application. The 4th application resulted in a dramatic decrease in N supply rates which is likely attributable to deteriorating conditions in the small pots of soil. The P supply rates were increased only at the high rate of hog manure application

b) Effect of hog manure application on plant growth
Plant growth under the growth chamber conditions was limited as indicated by the low yields. The biomass yields increased with each application of hog manure. The grain yields increased up to the 2nd hog manure application in the clay soils and after each hog manure application in the loam soils.

c) Effect of hog manure application on soil crusting strength
Hog manure applications increased soil crusting strength in the clay soils only. This was evidenced after the 2nd and 3rd application. However, the effect was absent following the 4th application of hog manure. This may well be the result of sodification of the soil surface as hog manure adds significant quantities of sodium salts. Unfortunately S.A.R. was only measured at the end of the experiment, and at that time the differences in soil strength had disappeared. The hog manure increased soil salinity (d). The increased concentration of electrolytes would reduce the sodicity effect of soil structure and hence reduce soil crusting.

d) Effect of hog manure application on soil salinization
Hog manure applications increased soil salinity, and following the 4th application the high hog manure application rate had dramatically increased the soil's electrical conductivity by > 3 dS/m. The evaporative demand in the growth chamber is very high which likely resulted a modest increase in soil salinity in all the soils.

e) Effect of hog manure application on soil pH.
The pH initially decreased after the 2nd application of hog manure. However, after the 3rd and 4th applications there was no longer a direct effect of manure applications on soil pH.

f) Effect of hog manure application on soil sodicity (SAR).
Hog manure increased soil sodicity of the loam textured soil only. The sodicity in all soils was high at the end of the experiment, which again points out the limitations of small pot experiments under growth chamber conditions.

g) Effect of hog manure application under fallow conditions
Under fallow conditions the effect of hog manure on soil nutrients was similar to that of the cropped conditions, with the exception that the increases in nutrients were larger. The most notable effect under fallow conditions was the increased salinity and sodicity. Hog manure increased soil salinity by 4.4 dS/m and by 5.7 dS/m following the medium and high rates of manure application on the clay soil, and by 4.7 dS/m following the high manure application on the loam soil. Hog manure applications increased the SAR by 1.5 units in the loam soil.

Significance of the growth chamber experiment results

The results suggest that repeated applications of high rates of hog manure not only result in excessive soil available nitrogen levels but also in deteriorating soil structure and soil chemical conditions, as well as reduced crop growth. Under fallow conditions the deterioration of soil chemical conditions from repeated applications of hog manure is more severe.

The experiment was carried out using small pots of soil that were kept in a growth chamber. The same soil was used for each cycle of hog manure applications and seeded to the different crops. Plot watering under the strong drying conditions in a growth chamber is done with high frequency. These conditions are therefore quite different from actual field conditions. The results must therefore be viewed as a worse case scenario in terms of what may occur under field conditions. The results are extremely valuable in interpreting the results from field research plots.

Table 1. The effect of repeated applications of liquid swine manure on soil conditions and crop growth in a growth chamber – Clay soil.

Manure	1st crop	2nd crop	3rd crop	4th crop
g.p.a				
	---------- Available soil nitrogen in µg/10cm^2 ----------			
0	19_a	34_a	248_a	14_a
5,000	580_{ab}	461_{ab}	1188_a	65_a
10,000	705_b	741_b	1874_b	127_b
	---------- Available soil phosphorus in µg/10cm^2 ----------			
0	2.08	0.75	1.90	1.68_{ab}
5,000	3.53	3.14	2.15	1.01_a
10,000	3.02	3.71	3.86	3.07_b
	---------- Plant biomass (dry) in Mg/ha ----------			
0	7.58	2.06_a	0.54_a	1.43_a
5,000	9.48	4.72_b	1.26_b	2.85_{ab}
10,000	9.24	3.96_{ab}	1.25_b	4.27_b
	---------- Plant grain weight in Mg/ha ----------			
0	0.054	0.867_{ab}	0.055	0.265
5,000	0.323	1.463_a	0.069	0.604
10,000	0.431	0.589_b	0.048	0.486
	---------- Soil crusting strength in kPa ----------			
0	ND	0.67_a	0.66_a	1.53
5,000	ND	0.83_{ab}	1.14_b	1.16
10,000	ND	1.16_b	1.50_c	1.22
	---------- Soil salinity (EC 1:1) in dS/m ----------			
0	ND	1.71	1.62	2.09_a
5,000	ND	1.73	1.35	4.38_b
10,000	ND	2.02	1.58	5.40_b
	---------- Soil reaction (pH 1:1) ----------			
0	ND	7.50_a	7.49	7.76
5,000	ND	7.22_b	7.52	7.81
10,000	ND	7.10_b	7.42	7.82
	---------- Soil sodicity (SAR) ----------			
0	ND	ND	ND	5.47
5,000	ND	ND	ND	4.97
10,000	ND	ND	ND	5.51

Hog manure treatment means followed by a different letter are significantly different ($P_{0.05}$)
First crop = Canola, second crop = barley, third crop = Canola, fourth crop = barley

Table 2. The effect of repeated applications of liquid swine manure on soil conditions and crop growth in a growth chamber – Loam soil.

Manure	1st crop	2nd crop	3rd crop	4th crop
g.p.a				
	---------- Available soil nitrogen in µg/10cm^2 ----------			
0	333_a	103_a	232_a	397
5,000	700_{ab}	728_b	523_a	108
10,000	989_b	471_b	1286_b	240
	---------- Available soil phosphorus in µg/10cm^2 ----------			
0	3.26	1.31_a	2.60_a	0.99_a
5,000	2.26	1.94_{ab}	1.39_a	2.94_a
10,000	2.54	5.45_b	4.50_b	4.97_b
	---------- Plant biomass (dry) in Mg/ha ----------			
0	4.72_a	1.07_a	0.77_a	1.35_a
5,000	10.32_b	3.39_b	1.08_a	1.50_a
10,000	11.27_b	3.79_b	2.51_b	4.48_b
	---------- Plant grain weight in Mg/ha ----------			
0	0.026	0.389_a	0.024	0.145
5,000	0.156	1.886_b	0.047	0.087
10,000	0.364	0.612_{ab}	0.029	0.462
	---------- Soil crusting strength in kPa ----------			
0	ND	0.82_a	1.40_{ab}	1.69_a
5,000	ND	1.15_b	1.26_a	1.58_{ab}
10,000	ND	1.32_b	1.90_b	1.18_b
	---------- Soil salinity (EC 1:1) in dS/m ----------			
0	ND	1.40_a	1.35	2.58_a
5,000	ND	2.55_{ab}	1.39	3.15_a
10,000	ND	3.92_c	1.65	5.91_b
	---------- Soil reaction (pH 1:1) ----------			
0	ND	7.08_a	7.28_a	7.84_a
5,000	ND	6.77_{ab}	7.50_b	7.69_b
10,000	ND	6.65_b	7.31_{ab}	7.83_a
	---------- Soil sodicity (SAR) ----------			
0	ND	ND	ND	4.27_a
5,000	ND	ND	ND	5.11_b
10,000	ND	ND	ND	6.60_c

Hog manure treatment means followed by a different letter are significantly different ($P_{0.05}$)
First crop = Canola, second crop = barley, third crop = Canola, fourth crop = barley

Table 3. The effect of repeated applications of liquid swine manure on soil conditions in a growth chamber – Clay soil fallowed over 4 cycles.

Manure	1st cycle	2nd cycle	3rd cycle	4th cycle
g.p.a				
	---------- Available soil nitrogen in µg/10cm^2 ----------			
0	122_{a}	397	507_{a}	143_{a}
5,000	275_{ab}	1113	830_{a}	655_{b}
10,000	892_{b}	1149	2026_{b}	365_{ab}
	---------- Available soil phosphorus in µg/10cm^2 ----------			
0	2.29	1.16_{a}	2.18_{a}	3.33
5,000	3.76	4.72_{b}	2.72_{a}	6.97
10,000	7.42	6.42_{b}	5.23_{b}	5.15
	---------- Soil crusting strength in kPa ----------			
0	ND	0.82	0.79	1.16
5,000	ND	0.69	0.90	1.17
10,000	ND	1.00	0.98	1.16
	---------- Soil salinity (EC 1:1) in dS/m ----------			
0	ND	1.74	2.56_{a}	2.00_{a}
5,000	ND	2.53	3.92_{ab}	6.40_{b}
10,000	ND	2.90	4.30_{b}	7.73_{b}
	---------- Soil reaction (pH 1:1) ----------			
0	ND	7.37_{a}	7.38_{a}	7.70_{a}
5,000	ND	7.18_{b}	7.10_{b}	7.60_{b}
10,000	ND	6.95_{c}	7.16_{b}	7.65_{ab}
	---------- Soil sodicity (SAR) ----------			
0	ND	ND	ND	4.77
5,000	ND	ND	ND	5.56
10,000	ND	ND	ND	4.76

Hog manure treatment means followed by a different letter are significantly different ($P_{0.05}$)

Table 4. The effect of repeated applications of liquid swine manure on soil conditions in a growth chamber – Loam soil fallowed over 4 cycles.

Manure	1st cycle	2nd cycle	3rd cycle	4th cycle
g.p.a				
	---------- Available soil nitrogen in µg/10cm^2 ----------			
0	424_a	155	764	116
5,000	419_a	420	1613	140
10,000	1540_b	558	1607	247
	---------- Available soil phosphorus in µg/10cm^2 ----------			
0	3.18	0.83_a	2.69_a	2.54
5,000	2.91	4.76_{ab}	2.39_a	2.64
10,000	5.28	11.63_b	5.63_b	4.01
	---------- Soil crusting strength in kPa ----------			
0	ND	1.07	1.88	1.13
5,000	ND	0.84	1.95	1.45
10,000	ND	0.77	1.73	1.45
	---------- Soil salinity (EC 1:1) in dS/m ----------			
0	ND	1.27_a	2.61_a	3.62_a
5,000	ND	2.00_{ab}	3.35_b	3.18_b
10,000	ND	2.93_b	4.55_b	8.36_b
	---------- Soil reaction (pH 1:1) ----------			
0	ND	7.35_a	7.26_a	7.69_a
5,000	ND	6.81_b	7.00_b	7.70_a
10,000	ND	6.29_c	6.83_b	7.46_b
	---------- Soil sodicity (SAR) ----------			
0	ND	ND	ND	4.38_a
5,000	ND	ND	ND	5.85_b
10,000	ND	ND	ND	6.18_b

Hog manure treatment means followed by a different letter are significantly different ($P_{0.05}$)

Personnel involved in the project

Summer students			
Vanessa Blechinger	May – Aug 1998	50% of full time	$800 per month
Carley Pollock	May – Aug 1999	Full time	$1,600 per month
	May – Aug 2000	50% of full time	$800 per month
	Sep – Nov 2000	part-time	$200 per month
Blaine van Melle	May – Aug 1999	50% of full time	$800 per month
Graduate students (M.Sc.)			
Grace Dauk	Jan 1999 – Dec 2000	full time	$1,000 per month
Takele Zeleke	May 2001	full time	on CIDA scholarship
Technician			
Sid Farkas	Sep – Oct 1998	full time	$3,500 per month
	May and Sep 1999	full time	$3,800 per month
	May and Sep 2000	full time	$3,800 per month
	May and Sep 2001	50% of full time	$3,800 per month

Acknowledgement of the Department's support

The contribution of ADF, Agriculture Development Fund was identified at presentations and at meetings

- Dauk, G.Y., M.C.J. Grevers, D.D. Knight and R.E. Farrell. 2000. Manure Induced Nitrous Oxide Flux in a Clay and Sand Soil in the Dark Brown Soil Zone of Saskatchewan. Proceedings of the 2000 Soils and Crops Workshop. Saskatoon, SK.
- Grevers, M.C.J. 1999. The Long-term Effect of Repeated Applications of Hog Manure on Soil Productivity. Page 8. Proceeding of the 1999 Annual Meeting of the Hokkaido Society of Agricultural Meteorology, Dec. 8, 1999, Obihiro, Japan.
- Grevers, M.C.J. and J.J. Schoenau. 2001. Hog Manure - A Dilute Fertilizer With Extra's. Proceedings of the 2000 Soils and Crops Workshop. Saskatoon, SK.
- Grevers, M.C.J. and J.J. Schoenau. 2002. The Effect of Repeated Applications of High Rates of Hog Manure on Soil Productivity in the Brown and Dark Brown Soil Zones. 2002 Soils and Crops Workshop. Saskatoon, SK.
- Grevers, M.C.J. and J.J. Schoenau. The long-term effect of repeated applications of hog manure on soil productivity in Saskatchewan. A.I.C./C.S.S.S. meeting, July, 1998. Vancouver, B.C,
- Grevers, M.C.J. and J.J. Schoenau. The long-term effect of repeated applications of hog manure on soil productivity. Manure Management '99. June 22-25, 1999 — Saskatoon, SK
- Schoenau, J.J., B. Assefa, and M.C.J. Grevers. Oct. 30, 2001. Effects of repeated Swine Manure Applications on Soil Quality in the Black Soil Zone. Prairie Swine Center. Environmental Seminar. 18 attendees.
- Schoenau, J.J., P. Mooleki, B. Assefa , M.C.J. Grevers, P. Qian, and G. Hultgreen. 2002. Benefits to Soil From Livestock Manure. Proceedings Direct Seeding Meetings.
- Zeleke, T, Grevers, M.C.J., and J.J. Schoenau. Can the Quality of Soil Structure be Maintained Following Repeated Applications of Hog Manure? 2002 Soils and Crops Workshop. Saskatoon, SK.